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ABSTRACT

In this first phase, job descriptions and need for trained concrete technologists within the concrete-using industries were determined by survey. The project staff created curriculum materials which were reviewed by outside authorities and put into workable lesson plans by a group of educational consultants. The result was a six-volume set of instructional materials covering 496 student-contact hours or 21 credit hours which could be used to implement 2-year concrete technology courses in post-secondary schools throughout the nation. Pilot programs were established in six junior colleges in the U.S. and Canada to test course content. Recommendations were for continued testing and eventual finalizing of the curriculum in Phase II, the adaptation of the curriculum to other educational endeavors in Phase III, and the creation of recruiting materials. The curriculum materials are available as VT 010 139-VT 010 141 and VT 010 150-VT 010 152. Outlines of these courses make up the bulk of this manuscript. (CD)

## INTERIM REPORT

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# RESULTS OF PHASE I OF THE DEVELOPMENT OF COURSE CONTENT AND TEACHING GUIDES FOR A TOTAL CURRICULUM IN CONCRETE TECHNOLOGY

James D. Piper
Howard C. Wiechman
John C. Seeger
Portland Cement Association
Skokie, Illinois

November 30, 1969

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

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Office of Education
Bureau of Research

## Acknowledgements

Special thanks are due the many individuals who gave of their time to assist with the technical review of the material contained in the concrete technology curriculum. These devoted professionals checked facts, made sure of illustrations, pondered the validity of discussion questions. Without their help the course material would lack the accuracy necessary to a viable curriculum. These reviewers are members of NRMCA and ACI or on the professional staff of PCA.

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## Summary

Description of the Problem. While the concrete-using industries have become increasingly technical, no schools offer courses that could prepare a student for many of the jobs available within the industry. Some "concrete technologists" are employed in industry but these individuals do not have the formal training implied by their titles. The National Concrete Technology curriculum is designed to provide the educational materials necessary to implement concrete technology courses in post-secondary schools throughout the nation.

Scope of Study and Objectives Pursued. The objectives of this grant were to create a two-year course at the post-secondary level in concrete technology.

Methods Used. A survey was made by the Advisory Group to the Project Administrative Team to determine job descriptions and need for trained concrete technologists within the concrete-using industries. Curriculum materials were created by the Project staff, reviewed by outside authorities, and put into workable lesson plans by a group of educational consultants. Pilot programs were established in 6 junior colleges in the U. S. and Canada.

Results Obtained. A six-volume set of instructional materials covering 496 student-contact hours or 21 credit hours; 6 ongoing pilot programs to test the course content; a list of additional schools indicating a desire to implement the program in 1970.

Recommendations for Further Action. The continued testing and eventual finalizing of the curriculum in Phase II, the adaptation of the curriculum to other educational endeavors in Phase III, creation of recruiting materials.

## Introduction

The nation's business is becoming increasingly technically oriented and the introduction of any one new technology will be reflected throughout the national economy. The growing complexity of contemporary endeavors has resulted in an increasing need for technical workers in all fields. Technology is a combination of the principles of science and engineering and the practical application. The technician or technologist, as the workers in the various fields of industrial technology are known, is the possessor of the practical skills of performance based on scientific and engineering principles. He functions as liaison between professional and laborer and also serves as a helper to the professional or a supervisor to the laborer.

One of the first reports to bring out the need for additional education to supplement the work of the engineering profession was the Wickenden and Spahr report made public in 1961.

> "A need exists in our post-secondary scheme of education for a large number of technical schools, giving a more intensive and practical training than that now provided by engineering colleges."

During the past few years many other reports have verified this tremendous need for technologists to occupy a significant and unique place between the professional and the laborer.

The November 17, 1969, issue of the Chicago Daily News quotes the National Industrial Conference Board as saying, "The technological revolution is going to run out of technicians in the 1970's unless steps are taken now to prevent it."

In an article, "The Need for Education in This Technological Age" in the Fall 1969 Occupational Outlook Quarterly, Labor Secretary George P. Shultz states,

"In the decade between 1965 and 1975, employment among professional and technical workers is expected to soar by 45.2 percent, while job opportunities for unskilled non-farm workers will drop by 3 percent. With this outlook, the years ahead hold very little promise for today's young people who have not prepared themselves for the technological society in which we will all be living."

The main purpose of the National Concrete Technology Curriculum Development Project was to develop course content and teaching materials to train "sub-professional" technologists for the concrete industries. This would provide a curriculum for an area of technical education where no course materials previously existed. The concrete technology curriculum will broaden the employment opportunities for nonacademic students and will help relieve the critical manpower shortages in the cement and concrete industries.

The curriculum development project is a three-phase program conducted under the auspices of the Office of Education of the Department of Health, Education, and Welfare, for the creation of a two-year college level curriculum in concrete technology, Phase I of the program (now complete) consisted of the curriculum design and creation and the preparation of all instructional aids such as lesson outlines, visual aids, laboratory manuals, and text materials for four courses in concrete technology and one course on quality assurance.

Phase II (a two-year field test in selected schools and the finalizing of the curriculum materials) is currently underway. Funding of Phase III (the adaptation of the curriculum material for other uses) will be requested in the near future.

In the selection and description of the support courses for the two-year course, it was necessary to consider the content of the courses offered in the average community college or vocational school as well as the skills and knowledge necessary to a concrete technologist.

The curriculum is designed to provide the educational tools necessary to the education of concrete technologists. Occupying a significant and unique place between the professional and the laborer, the technologist must be familiar with the responsibilities, talents, and terminology of both. Well-trained technologists increasingly assume many of the routine duties of professionally trained people.

## Methods

To accomplish the objectives of this project it was deemed advisable to form a working Advisory Group to the Administrative Team to broaden the scope of the Project staff. On August 26, 1968, 41 letters of invitation were sent to officers of selected allied industry associations asking their cooperation as members of the Advisory Group. Twenty-seven associations readily accepted and have cooperated with the Project staff by supplying technical information and resource materials. (A list of associations represented in the Advisory Group is attached to this report as Appendix A).

In order to obtain occupational data pertaining to concrete technologists, a survey was made of the Advisory Group. Information was sought regarding job titles and descriptions, annual industry needs for personnel with such training, and the relevance of the curriculum to the jobs mentioned. The overall returns were excellent and several of the associations sent questionnaires to their membership for an in-depth study. (Sample questionnaires and chart of the total survey results are attached as Appendix B).

The American Society of Concrete Constructors, the American Concrete Institute, and the National Ready Mixed Concrete Association were especially helpful in securing the needed information.

As a result of the industry analysis, starting salaries for persons completing this program were placed in a range from $475 to $1,500, depending upon job title and regional location. All industry groups indicated an urgent need for people with the qualifications of a concrete technologist to fill current and future vacancies.

The job titles most often cited by polled associations can be grouped in five main catagories.

I. Research and Development
    a. Experimental Testing
    b. Systems Analysis
    c. Industrial Relations
    d. Data Evaluation
    e. Estimating
II. Management and Supervision
    a. Cost Analysis
    b. Systems Analysis
    c. Industrial Relations
    d. Data Evaluation
    e. Estimating
III. Production
    a. Quality Control
    b. Inspection

c. Operations Research
d. Product Testing
e. Data Compilation
f. Cost Control

IV. Sales
a. Sales
b. Marketing
c. Product Installation
d. Technical Services

V. Construction
a. Quality Control
b. Inspection
c. Supervision
d. Records Control

Regular meetings of representatives of the Eastern Illinois Development and Service Unit (EID&SU) and the Project staff, resulted in the growth of a mutual understanding of the major objectives and goals of the Project and agreement of the best methods of attaining a viable and meaningful curriculum. Compatability between the two groups created the spirit of cooperation necessary to the success of the Project. A procedural system was established and functions appropriate to EID&SU and to the Project staff were assigned. The interaction between the groups resulted in well-balanced lesson materials, with EID&SU responsible for the total curriculum content and all related materials.

A nationwide random survey of community colleges and technical schools was conducted by EID&SU. The purpose of the survey was to (1) determine if the suggested curriculum was within the capability of most students; (2) find out if the schools had the physical plant necessary to add such a course to its curriculum; (3) obtain an opinion of the proposed class and credit hours; (4) assess the impact of such a curriculum on school and faculty; and (5) secure an expression of interest in the course on the part of school administrators. Modifications in the course content and total hours were made as a result of the survey and a list of interested schools was established.

Assignments of responsibilities were made to the Project staff subject matter specialists for all unit topics in the curriculum and a critical path chart was established for the work flow. As each unit was developed to a semi-final stage, it was sent out to various authorities for technical review. After this review, modifications were made where necessary and the unit was then sent to EID&SU to be divided into daily class units and instructor's presentation outlines and other educational aids were prepared.

## Results

Because of the broad spectrum of job possibilities for the concrete technologists, it was necessary to prepare a curriculum with a broad course content. Technical information has been combined with business management and personal skill development in a manner that will be meaningful and useful to the student.

A workable two-year curriculum based on seventy semester hours of study covers five courses on concrete technology and quality assurance for which instructional material has been prepared by the Project staff. These five courses are:

Principles of Concrete
Concrete in the Field, I
Concrete in the Field, II
Special Concretes and Field Problems
Quality Assurance.

(An outline of the content of each semester course is attached to this report as Appendix C).

A volume of laboratory exercises to supplement the five courses is also included with the instructional material. (An example of one complete instructional unit on air entrainment (16, 17, and 18 of the course on the Principles of Concrete) is included as Insert I but is not a part of the microfilmed report.)

The remainder of the curriculum consists of courses in the fields of mathematics, science, humanities, business, and various technical subjects. The outline of the two-year curriculum is attached as Appendix D and the breakdown of subject content by student contact hours and percentage of total time is included as Appendix E.

Contact with schools interested in becoming sites for pilot programs for Phase II of the Project was continued throughout the year. Final commitments were made during the summer of 1969.

Four junior colleges in the United States and two in Canada were selected as pilot schools to field test the developed curriculum materials. (While the two schools in Canada are participating as pilot schools, there are no expenditures of federal funds for these programs).

The pilot schools, the student enrollment in the concrete technology course, and a brief description of the implementation of the program follows.

| School | Fall 1969 Enrollment | Remarks |
|---|---|---|
| Daytona Beach Junior College<br>Daytona Beach, Florida | 5 | Twenty-four industry scholarships offered. Excellent press coverage. Television spot (1 minute) plus 12-minute feature on Concrete Technology. Problem: insufficient time to reach students. Program implemented after high schools closed in June. Will operate with existing students and contact high schools prior to start of next term. |
| Lake Land College<br>Mattoon, Illinois | 14 | One industry scholarship offered. Excellent press coverage although no radio or television. New school--now building facilities--new staff. Good student response due to the fact that 3 area schools graduated students from a 2-year pilot program in concrete construction. Eight students heard about course through high school counselors, 5 through newspapers, and 1 through personal contact. |
| Maricopa Technical College<br>Phoenix, Arizona | 20-25 | Scholarships offered in press releases. Program established as "Day-Evening"--concrete courses in evening, support courses during the day. Preliminary enrollment over 40 but school limited it to 20-25. All enrollments are for evening classes only as an industry upgrading program. No day students. Problem: insufficient time to recruit at high schools. |
| Northeastern Junior College<br>Sterling, Colorado | 1 | Information on scholarships not available. Good industry support and adequate newspaper coverage. Problem: insufficient time to recruit at high schools. School will modify program. No |

| | | |
|---|---|---|
| | | concrete courses during the first quarter and will double up in second quarter. School convinced of ability to recruit students for second quarter and will continue program. |
| George Brown College<br>Toronto, Ontario | none | School awaiting formal approval from Provincial Department of Education. School is enthused about program. Will offer National Concrete Technology as a separate course, but start students in Construction Technology curriculum,which will be a common first approach. Will change later. Should start September 1970. |
| New Brunswick Institute of Technology<br>Moncton, New Brunswick | none | School awaiting formal approval from Provincial Department of Education and salary and occupational survey by Department of Manpower and Immigration. School enthused about program. All technology curricula are now on a common first year. Will start concrete courses in fall of 1970. |

This final report is being submitted November 30, 1969, rather than August 31, 1969, in accordance with the statement of the project officer granting a 90-day extension of the grant period.

The curriculum materials could not be completed by August 31, due to a backlog of printing and other production difficulties. In addition, difficulties in finalizing plans with various pilot schools further delayed the final stages of Phase I. (This problem is discussed in greater detail in "Recommendation".)

## Conclusion

As of November 30, 1969, the concrete technology curriculum has been completed in its preliminary form. Pilot schools have been selected for the testing of the curriculum materials and programs have been implemented in these 6 schools. (A complete list of the schools and addresses is included in this report as Appendix F). In addition, other schools have been contacted for possible inclusion as pilot schools in the 1970 school year. (These schools are listed in Appendix G.)

Qualified instructors have been obtained for each of the pilot programs. In one instance, a retiring PCA research professional agreed to extend his career and teach one of the pilot courses. In another instance, a PCA member company supplied a knowledgeable professional employee to instruct the class.

Throughout Phase I the assistance of the aforementioned associations allied with the concrete-using industries has been of inestimatible value to the Project staff. Whether help was requested with job analysis, technical review, or other problems, their assistance was always readily forthcoming and their cooperation outstanding. The concrete technology curriculum is the product of a total industry effort.

During the final months of Phase I, evaluation forms were prepared to gather feedback information from Phase II--the program of systematically testing the total curriculum in pilot schools. Copies of the questionnaires prepared for Instructors and students are included in this report as Appendix H.

## Recommendations

The writing of the initial curriculum materials is the major portion of effort in the three-phase total program. The testing of this curriculum in pilot schools and the ensuing rewriting to put the curriculum in final form, are also of vital importance to the validity of the course content. Through testing it will be possible to determine how students react to the various units and where there is need for more--or less--elaboration. The instructors will be able to make judgments of course content based on the background of the students. The relative value of support courses can also be determined and, in some cases, these courses altered to better fit the needs of a total concrete technology course.

At the end of Phase II the national curriculum in concrete technology will be in final form and it is in Phase III of the project that the great rewards of the previous work can be reaped. Various portions of the curriculum can be extracted, rewritten to some extent, and presented as short courses, supplements to apprenticeship programs, units in professional programs for engineers, architects, and others; adult continuing education programs, and other important uses.

The Progress Report for Project No. 8-0042, dated January 10, 1969, states,

"Students are much more likely to enroll in technology programs they are familiar with than new programs. (Thus outdated programs are perpetuated not always by need but simply because they exist and students know of them.) No such awareness exists of the new programs being developed in concrete technology or opportunities in the concrete industries."

The lack of recruitment materials to use in interesting prospective students in the concrete technology was a serious problem during the establishment of the pilot programs. In one instance, (Daytona Beach Junior College) even with 24 available industry-sponsored scholarships, good newspaper and television coverage, only 5 students were started in the course. Students have not heard of concrete technology and have few ideas of what a concrete technologist does or what the job opportunities in the field are.

It is strongly suggested that some materials which can help with recruitment be created and that the first major effort be a film to tell the story of concrete technology and of how the concrete technologist is useful to industry. This should be aimed at the student but should be helpful in interesting high school counselors in the program, too. In addition to this film, a brochure or leaflet should be produced which could reiterate some of the major points made in the film and which would be inexpensive enough to use as a "give-away" in conjunction with the film.

It would also be highly desirable to create a more detailed booklet or brochure on the concrete technology program written for school administrators at the secondary and post-secondary levels. This brochure should explain both the proposed two-year course in concrete-related subjects designed for the secondary schools. The various ways in which these two curricula can be used in regular school use, adult continuing education, to supplement other construction courses, and so forth, should also be discussed in general. This recruitment piece could be used to interest schools in implementing such programs and would be helpful in making counselors aware of the importance of a concrete-related curriculum.

The January 10 Progress Report further states,

"The selection of pilot schools for Phase II of the Project may require personal visits. Initial contact with several schools has indicated a need for detailed explanation of the course content."

Because the instructor seminar was eliminated from the original proposal, it has been necessary to develop pilot school interest by working with each school individually. The seminar would have permitted working with a group of schools. The necessity of spending an increased amount of time on this matter of the development of pilot schools severely limited the number of schools which it was possible to contact. The lack of adequate funds for travel also made contact with pilot schools extremely difficult.

The first paragraph of the initial proposal for a grant for the "Development of Course Content and Teaching Guides for a Total Curriculum in Concrete Technology (Phase I)" states:

"The purpose of the research project described in this proposal is (1) to ascertain specific knowledge and skills necessary for employment in the various occupational classifications in the concrete industries, and (2) to develop the course content and related instruction guides that will assist vocational and technical educators to meet the training needs of students entering those industries."

The six volumes of "course content and related instruction guides" are a strong witness to the face that the monies granted by the Office of Education have been used to this end.

# APPENDIX A. --ADVISORY GROUP TO THE ADMINISTRATIVE TEAM

American Concrete Paving Association
American Concrete Pipe Association
American Society of Civil Engineers
American Society of Concrete Constructors
American Road Builders' Association
Architectural Precast Association
Associated General Contractors of America
Cellular Concrete Association, Inc.
Concrete Joint Institute
Concrete Reinforcing Steel Institute
Expanded Shale Clay and Slate Institute
Flexicore Manufacturers Association
Mason Contractors Association of America
Mo-Sai Institute, Inc.
National Concrete Burial Vault Association
National Concrete Masonry Association
National Crushed Stone Association
National Precast Concrete Association
National Slag Association
National Society of Professional Engineers
National Swimming Pool Institute
Perlite Institute, Inc.
Prestressed Concrete Institute
Tile Contractors' Association of America
Vermiculite Institute
Wire Reinforcement Institute

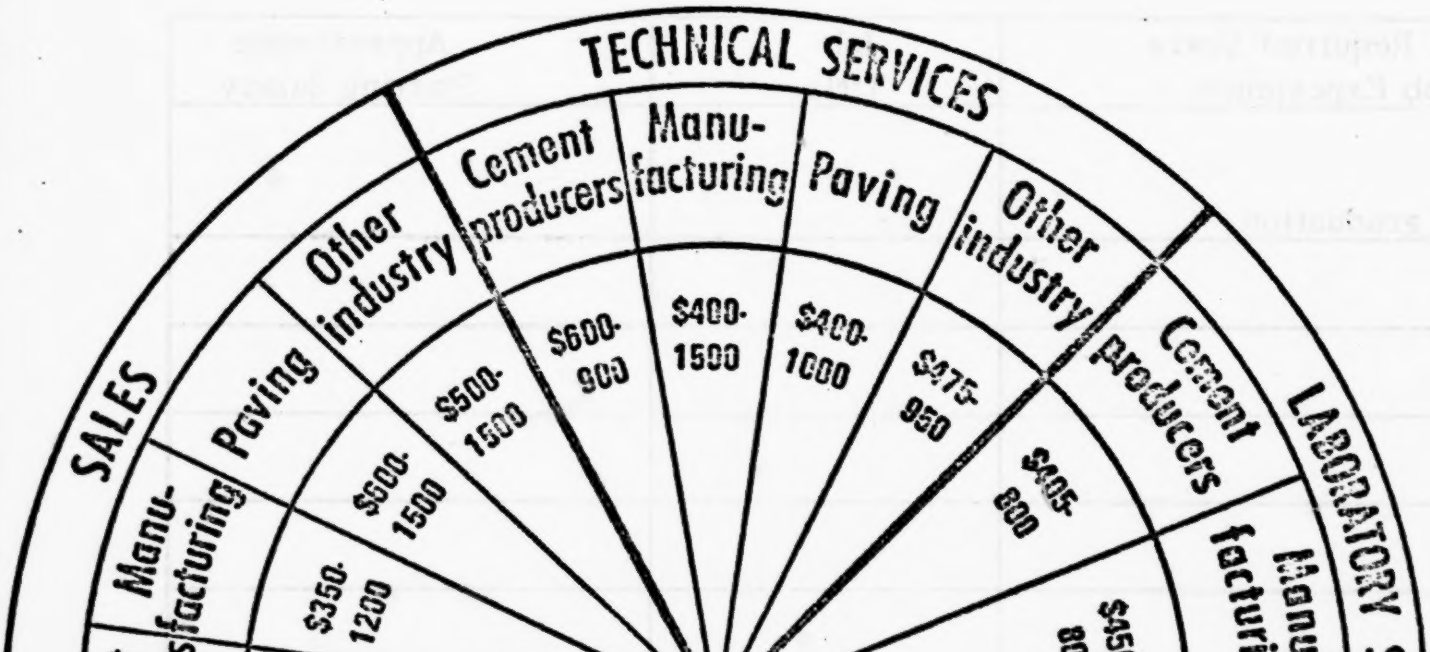
## APPENDIX B.--NATIONAL CONCRETE TECHNOLOGY CURRICULUM PROJECT

### Concrete Technologist Employment Study

1. Please list the job classifications (by title) in your organization which require the educational experience provided by the attached curriculum.

| Initial Required Years of Job Experience | Job Title | Approximate Starting Salary |
|---|---|---|
| 1. On graduation | | |
| 2. | | |
| 3. | | |
| 4. | | |
| 5. | | |
| 6. | | |

2. How many concrete technologists are regularly employed in your company? __________
3. How many concrete technologists are you required to hire annually to maintain the above figure? ________
4. How many concrete technologists do you anticipate adding to your staff annually in the next five years? ________
5. What is your opinion of the enclosed course outline? What changes do you suggest? What courses do you feel are unimportant? What would you add or drop? (Please continue your remarks on the back.) __________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
6. Type of business, organization, or agency: ______________________


TECHNICAL SERVICES
Cement producers
$600-900
Manufacturing
$400-1500
Paving
$400-1000
Other industry
$475-950
LABORATORY SERVICES
Cement producers
$405-800
Manufacturing
$450-800
Other industry
$600-800
PRODUCTION
Cement producers
$715
Manufacturing
$400-1000
Paving
$450-1200
Other industry
$500-1200
MANAGEMENT & ADMINISTRATION
Manufacturing
$400-1150
Paving
$450-1500
Other industry
$500-1415
SALES
Cement producers
$700-900
Manufacturing
$350-1200
Paving
$600-1500
Other industry
$500-1500

## APPENDIX C. --OUTLINES OF THE COURSES PREPARED BY THE PROJECT STAFF

### I. PRINCIPLES OF CONCRETE

| Session No. | |
|---|---|
| 1. | Introduction to Course |
| 2-3. | Job Opportunities |
| 4-6. | History of Cement and Concrete Industries |
| 7-9. | Uses of Concrete and Concrete Products |
| 10-11. | Materials for Concrete--Cement |
| 12. | Materials for Concrete--Water |
| 13-15. | Materials for Concrete--Aggregates |
| 16-18. | Air-Entrained Concrete |
| 19-20. | Review and Mid-Term Exam |
| 21-22. | Materials for Concrete--Admixtures |
| 23-30. | Essentials of Concrete |
| 31-42. | Design of Concrete Mixtures |
| 43-45. | Mixing Concrete |
| 46-48. | Review |

### II. CONCRETE IN THE FIELD-I

| Session No. | |
|---|---|
| 1. | Introduction to Course |
| 2-4. | Handling of Concrete--Transporting |
| 5-7. | Handling of Concrete--Placing |
| 8-10. | Tools and Equipment for Finishing Concrete |
| 11-19. | Finishing of Concrete |
| 20-21. | Review and Mid-Term Exam |
| 22-27. | Jointing of Concrete |
| 28-33. | Volume Changes and Crack Control |
| 34-43. | Soil-Cement |
| 44-45. | Fire Resistance of Concrete |
| 46-48. | Review |

### III. CONCRETE IN THE FIELD-II

| Session No. | |
|---|---|
| 1. | Introduction to Course |
| 2-6. | Curing of Concrete |
| 7-9. | Hot-Weather Concreting |
| 10-12. | Cold-Weather Concreting |
| 13-21. | Forms for Concrete |
| 22-23. | Review and Mid-Term Exam |
| 24-29. | Requirements for Reinforced Concrete |
| 30-35. | Prestressed and Precast Concrete |
| 36-45. | Estimating |
| 46-48. | Review |

## IV. SPECIAL CONCRETES AND FIELD PROBLEMS

| Session No. | |
|---|---|
| 1. | Introduction to Course |
| 2. | The Lightweight Concrete Spectrum |
| 3. | Insulating Concretes |
| 4-9. | Structural Lightweight Concrete |
| 10. | Heavyweight Concrete |
| 11-12. | Decorative Concrete |
| 13-15. | Non-Plastic Mixes |
| 16-18. | Concrete Masonry--Manufacture |
| 19-21. | Concrete Masonry--Construction and Mortars |
| 22-23. | Review and Mid-Term Exam |
| 24-26. | Concrete Pipe--Manufacture |
| 27-29. | Concrete Pipe--Construction |
| 30-37. | Analyzing Concrete Field Problems |
| 38-45. | Legal Aspects of Concrete Construction |
| 46-48. | Review |

## V. QUALITY ASSURANCE

| Session No. | |
|---|---|
| 1-2. | Introduction |
| 3-4. | Scope of Quality Assurance |
| 5-8. | Standards, Specifications and Test Methods |
| 9-10. | Collection and Preparation of Data |
| 11-15. | Statistical Analysis of Data |
| 16-17. | Inspection and Testing of Materials |
| 18-19. | Review and Mid-Term Exam |
| 20-23. | Job Site and Before Concreting Inspection |
| 24-27. | Inspection During Concreting--Plastic Concrete |
| 28-30. | Inspection After Concreting--Hardened Concrete |
| 31-32. | Review |

## APPENDIX D. --TENTATIVE CONCRETE TECHNOLOGY CURRICULUM

### FIRST YEAR

| First Semester: | Class Hr/Wk | Lab Hr/Wk | Credit Hr/Semester |
|---|---|---|---|
| Technical Math I | 4 | - | 4 |
| Blueprint Reading - Graphics | 1 | 3 | 2 |
| Technical Physics (Mechanics) | 3 | 3 | 4 |
| Basic Communications (Report Writing) | 3 | - | 3 |
| *Principles of Concrete | 3 | 3 | 4 |
| | 14 | 9 | 17 |

| Second Semester: | | | |
|---|---|---|---|
| Technical Math II | 4 | - | 4 |
| Technical Chemistry | 3 | 3 | 4 |
| Strength of Materials I | 3 | - | 3 |
| Elementary Surveying | 1 | 3 | 2 |
| *Concrete in the Field I | 3 | 3 | 4 |
| | 14 | 9 | 17 |

### SECOND YEAR

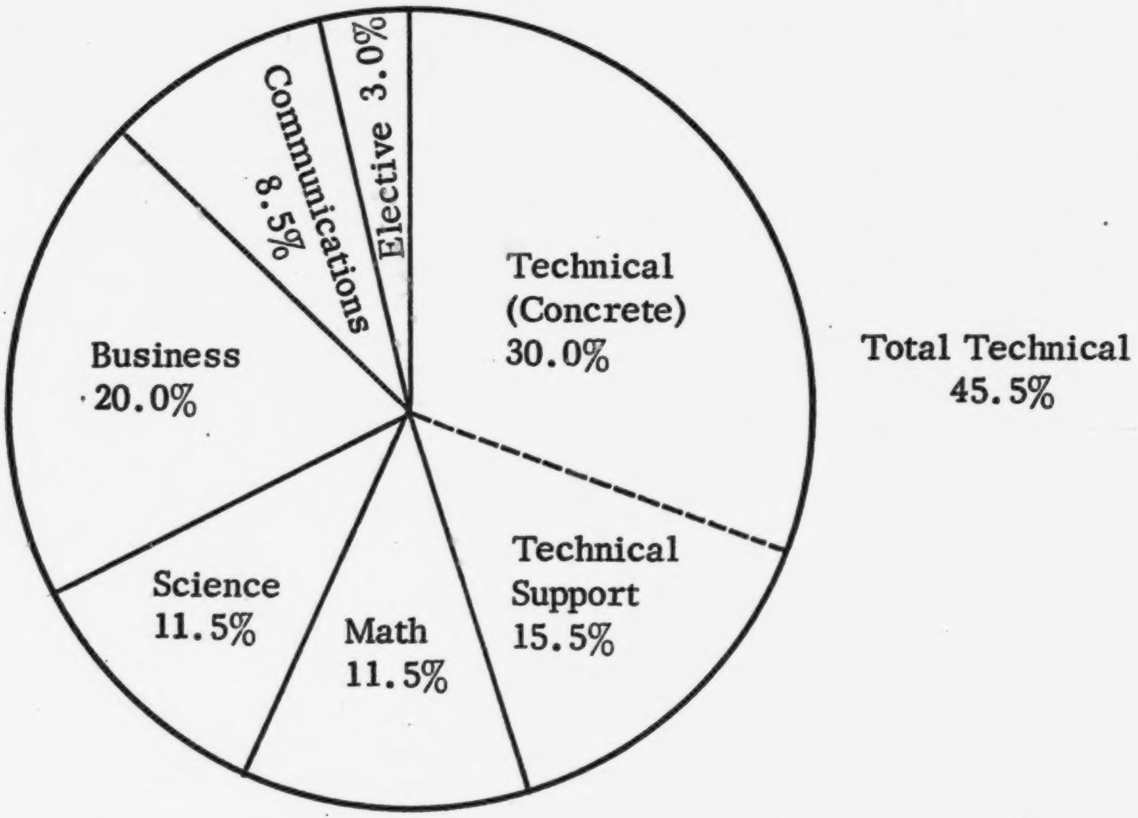
| Third Semester: | | | |
|---|---|---|---|
| Elective | 2 | - | 2 |
| Industrial Psychology | 3 | - | 3 |
| Introduction to Contract Law | 2 | - | 2 |
| Strength of Materials II | 3 | 3 | 4 |
| Basic Salesmanship | 3 | - | 3 |
| *Concrete in the Field II | 3 | 3 | 4 |
| | 16 | 6 | 18 |

| Fourth Semester: | | | |
|---|---|---|---|
| Basic Concrete Structural Design | 2 | 3 | 3 |
| Public Speaking | 3 | - | 3 |
| Industrial Relations | 3 | - | 3 |
| Small Business Management | 3 | - | 3 |
| *Quality Assurance | 2 | - | 2 |
| *Special Concretes & Field Problems | 3 | 3 | 4 |
| | 16 | 6 | 18 |
| **Total Hours** | 60 | 30 | 70 |

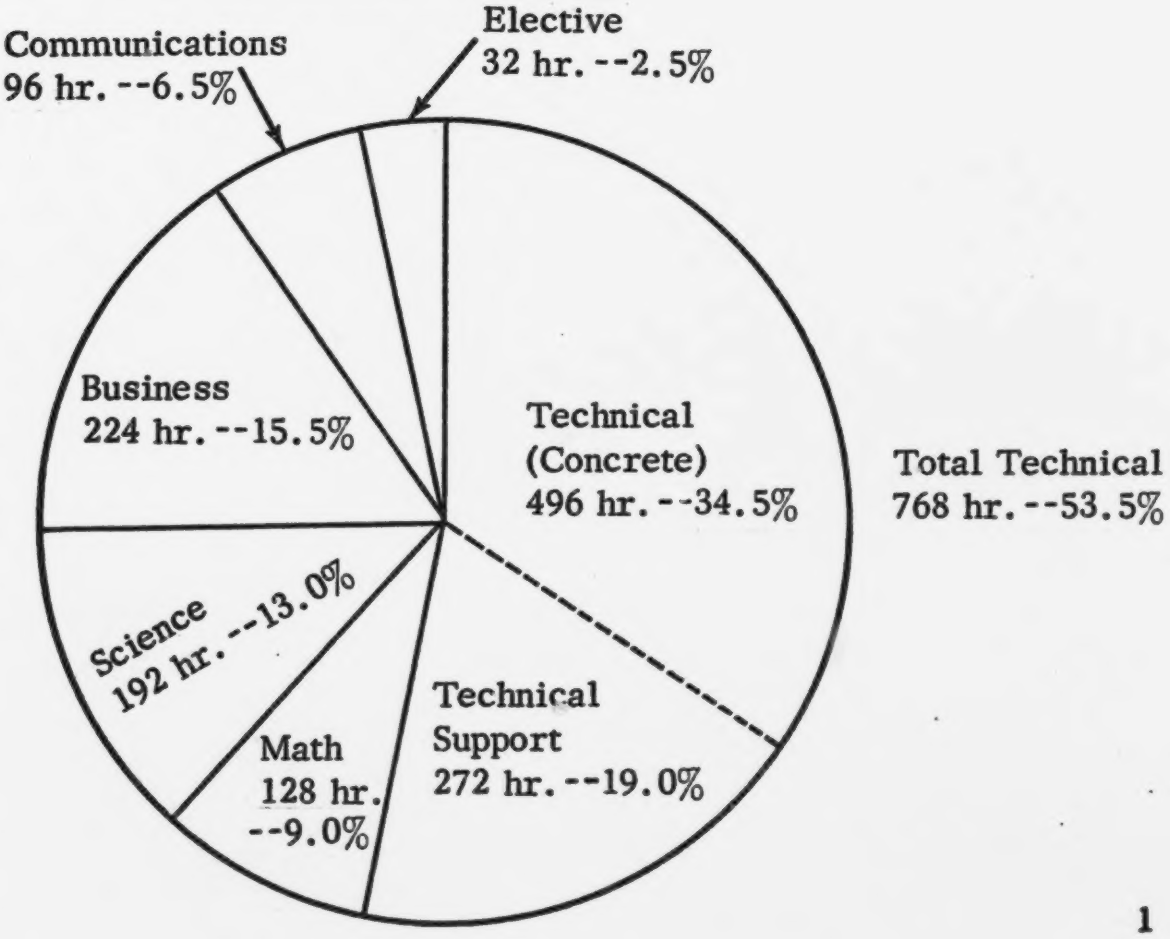
*Courses written by Project Staff

## APPENDIX E.

70 SEMESTER HOURS



1,440 CONTACT HOURS



# APPENDIX F.--NATIONAL CURRICULUM TECHNOLOGY PILOT SCHOOLS
# FALL 1969

| United States Schools | Contact |
|---|---|
| Daytona Beach Junior College<br>Post Office Box 1111<br>Daytona Beach, Florida 32015 | Mr. Ed Ek<br>Director, Division of Technology |
| Lake Land College<br>1921 Richmond<br>Mattoon, Illinois | Mr. S. H. Westby<br>Instructor, Concrete Technology |
| Maricopa Technical College<br>106 East Washington Street<br>Phoenix, Arizona | Mr. Norbert Bruemmer<br>Dean of Instruction |
| Northeastern Junior College<br>Sterling, Colorado | Mr. Hilbert Kahl<br>Director<br>Vocational, Technical Education |
| **Canadian Schools** | |
| George Brown College of Applied Arts and Technology<br>Terauley Campus<br>51 Terauley Street<br>Toronto, Ontario | Mr. Jack Stirling<br>Chairman,<br>Architectural Technology |
| New Brunswick Institute of Technology<br>1234 Mountain Road<br>Post Office Box 2100, Postal Station A<br>Moncton, New Brunswick | Mr. Boyd Touchie<br>Chief Instructor<br>Civil Technology |

## ADDITIONAL SCHOOLS BEING CONTACTED FOR SPRING 1970 PILOT PROGRAM

| United States Schools | Contact |
|---|---|
| Columbus Technical Institute<br>557 Mt. Vernon Avenue<br>Columbus, Ohio 43215 | Mr. Russell W. Jordan<br>Director of Education |
| District One Technical Institute<br>620 West Clairemont Avenue<br>Eau Claire, Wisconsin 54701 | Mr. Lyle Wandrei<br>Technical Education Supervisor |
| Hagerstown Junior College<br>751 Robinwood Drive<br>Hagerstown, Maryland 21740 | Mr. Joseph M. Snarponis<br>Coordinator of Technician Education |
| Lincoln Vocational Technical School<br>Public School Administration Building<br>Box 200<br>Lincoln, Nebraska 62501 | Mr. James B. Lightbody<br>Assistant Superintendent |
| Northeast Louisiana State College<br>Monroe, Louisiana 71201 | Professor Thurman Potts<br>Head, Department of Building Construction |
| Pasadena City College<br>1570 East Colorado Boulevard<br>Pasadena, California 91106 | Mr. Lawrence A. Johannsen<br>Chairman, Department of Engineering and Technology |
| Prince George's Junior College<br>Largo, Maryland | Mr. William H. Snyder<br>Associate Dean for Technical Education |
| Racine School of Vocational, Technical and Adult Education<br>800 Center Street<br>Racine, Wisconsin 53403 | Mr. Howard M. Heigl<br>District Director |
| San Bernardino Valley College<br>San Bernardino, California | Mr. Henry A. James<br>Head, Engineering and Applied Science Department |
| Tacoma Vocational-Technical Institute<br>1101 South Yakima Avenue<br>Tacoma, Washington 98405 | Mr. Bruce Brennan<br>Administrative Director |

| | |
|---|---|
| University of Maine<br>101 Boardman Hall<br>Orono, Maine 04473 | Professor Wayne A. Hamilton<br>Associate Professor and Department Head, Department of Civil Engineering |
| Vincennes University<br>Vincennes, Indiana 47591 | Mr. Jack L. Bottenfield<br>Assistant to the President |
| Warren Woods Public Schools<br>27100 Schoenherr Road<br>Warren, Michigan 48093 | Mr. James D. Vlaz<br>Director, Vocational Education |

Canadian Schools

| | |
|---|---|
| British Columbia Institute of Technology<br>3700 Willingdon Avenue<br>Burnaby 2, British Columbia | Mr. Ralph Carey<br>Chairman, Technological Planning Committee |
| Southern Alberta Institute of Technology<br>1301 - 16th Avenue<br>Calgary 41, Alberta | Mr. W. G. Leslie<br>Head, Structures Department |

## APPENDIX G. --INSTRUCTORS' CURRICULUM EVALUATION

School____________________ Date________________
Department________________ Instructor________________
Subject____________ Session Nos. ________ Laboratory Nos. ____

1. Provide your reactions to the material presented in this area of instruction by checking the appropriate box. Feel free to add additional categories. Where major problems exist, please define them and, if possible, recommend solutions (see Page 2).

| | Category Evaluated | Excellent | Satisfactory | Fair | Major Problem |
|---|---|---|---|---|---|
| CLASSROOM SESSIONS | Related Activities | | | | |
| | Tools and Materials | | | | |
| | Presentation Outlines | | | | |
| | Teaching Techniques/Aids/Devices | | | | |
| | Related Information | | | | |
| | Discussion Questions | | | | |
| | Continuity of Material | | | | |
| | Level of Instruction | | | | |
| | Student Interest | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |
| LABORATORY SESSIONS | Instructor's Notes | | | | |
| | Apparatus List | | | | |
| | Materials List | | | | |
| | Instructor's Demonstration | | | | |
| | Student Procedure | | | | |
| | Data Sheets (where applicable) | | | | |
| | Report Instructions | | | | |
| | Discussion Questions | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

# DISCUSSION OF MAJOR PROBLEM AREAS

| Category | Description of Problem | Recommendations |
|---|---|---|
| | | |

## GENERAL INFORMATION

2. **What additional instructional materials have you used that have been helpful in your presentations?**

3. **Do the Presentation Outlines help in presenting the material to the students?**

   **Yes______ No______**

   **If no, indicate the source of difficulty.**

4. **Have you used any slides, transparencies, films or other visuals in your presentations?**

   **Yes______ No______**

   **If yes, what did you use?**

5. **Are the suggested visuals and teaching aids satisfactory?**

   **Yes______ No______**

   **If no, indicate how they can be improved?**

6. **List any other comments or suggestions not covered.**

7. In order for the project staff to improve the Presentation Outlines, please return a photo copy of your outlines showing your modications, additions, or corrections.

8. STUDENT PERFORMANCE

In your estimation, as the classroom instructor, which of the below best describes the progress of your students.

a. ______ All the students are progressing well above expectations.

b. ______ Most of the students are progressing well, meeting average expectations.

c. ______ Most of the students are having difficulty with this unit - below expectations.

d. ______ All the students are having difficulty. Extremely poor progress. If either "c" or "d" above are checked, briefly describe what you believe to be the source of difficulty.

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

______________________________________________

9. In your estimation the students are

| | % of students |
|---|---|
| Well satisfied | ______ |
| Satisfied | ______ |
| Less than satisfied | ______ |
| Dissatisfied | ______ |

If dissatisfied, briefly describe what you believe to be the prime source for this dissatisfaction.

______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________

10. a. Were any examinations given for this subject?

Yes _____ No _____

b. How many students fell within the following distribution?

100-95______ 94-90 ______ 89-85 ______ 84-80 ______
79-75______ 74-70 ______ 69-65 ______ 64-60 ______
59-50______ below 50______

c. What was the minimum passing grade for this examination?

d. Please include a copy of your examination.

## APPENDIX H. --STUDENTS' CURRICULUM EVALUATION

School ______________________________ Date ____________
Classroom Subject ____________________________________
Laboratory Subject ___________________________________

GENERAL INSTRUCTIONS: You have just completed a unit of study in the Concrete Technology Curriculum. As a result, you are being asked to participate in the curriculum evaluation. Answer all questions in your own words, and use additional paper if necessary. Please evaluate only the subject matter. Do not attempt to evaluate your instructor. Complete the questionnaire as soon as possible. Do not sign. Use the self addressed envelope provided and mail the questionnaire directly to:

Project Director
PCA-NRMCA-ACI National Concrete Technology Curriculum Project
% Portland Cement Association
Old Orchard Road
Skokie, Illinois 60076

1. In terms of your ability to understand this subject, use the following rating scale and mark your answers with a check.
   a. Difficult to understand
   b. Understandable
   c. Too easy

| CLASSROOM SUBJECT TITLES | a | b | c |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

| LABORATORY SUBJECT TITLES | a | b | c |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

2. For each classroom subject given a rating of "a," please give at least one reason for the difficulty.

| CLASSROOM SUBJECT TITLE | REASONS FOR THE DIFFICULTY |
|---|---|
| | |
| | |
| | |

3. For each laboratory subject given a rating of "a", please give at least one reason for the difficulty.

| LABORATORY SUBJECT TITLE | REASONS FOR THE DIFFICULTY |
|---|---|
| | |
| | |
| | |

4. Analyze this subject for both the classroom and laboratory work by placing a check in the appropriate box. Add additional items if necessary.

| ITEM | CLASSROOM | | | LABORATORY | | |
|---|---|---|---|---|---|---|
| | No Problem | Some Problem | Major Problem | No Problem | Some Problem | Major Problem |
| Amount of material | | | | | | |
| Reading level | | | | | | |
| Interest level | | | | | | |
| Technical level | | | | | | |
| Homework | | | | | | |
| Discussion time | | | | | | |
| Laboratory time | | | | | | |
| | | | | | | |

5. For those items that have been checked as "major problem", give a least one example of this problem.

| ITEMS | CLASSROOM EXAMPLES | LABORATORY EXAMPLES |
|---|---|---|
| | | |
| | | |
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6. In reference to this subject, what stands out as your most positive experience?

What stands out as your most negative experience?

7. List any additional comments and/or suggestions that you as a student feel would improve this section of the course.

8. Based upon examinations or your opinion, what is your academic standing? Please check one.

| | Upper 10% | Upper 25% | Upper 50% | Lower 50% |
|---|---|---|---|---|
| This specific concrete course | | | | |
| The entire term's work (all courses) | | | | |

## Lab. No. 8
## DETERMINATION OF THE AIR CONTENT OF CONCRETE

### APPARATUS FOR SESSION

Worktable with suitable space, at hip height.
Mixing pans (one per group).
Trowels (two per group).
Concrete mixer, tilting drum or pan, 1-1/2-to 2-cu. ft. capacity.
Large water cans.
One-gal. capacity pouring cans (one for each meter).
Cover plate for determining unit weight (one per group).
Small plastic bottles to hold alcohol (one per group).
Syringe or alcohol spray.
Tamping rod, soft-tipped.
Mallet with a rubber or rawhide head or wooden 2x2 billet.
Strikeoff bar.
Metal funnel.
Slotted spoon.

### Equipment for Measuring Air Content

High-silhouette pressure air meter, with 1/2-or 1/4-cu. ft. capacity bowl, and auxiliary equipment or low-silhouette pressure air meter, with auxiliary equipment.
Roll-A-Meter volumetric device, with auxiliary equipment.
Chace AE-55 air indicator, with auxiliary equipment.

### Equipment for Weighing Water

Scale sensitive to 0.01 lb., with minimum capacity of 20 lb.
Scale sensitive to 0.5 g., with 5-kg. capacity.
Tare bucket for weighing water, plastic with pour spout, with minimum capacity of 2 gal. (one per group).

## Equipment for Weighing Cement

Scale sensitive to 0.01 lb., with minimum capacity of 20 lb.
Tare scoop for weighing cement (one for entire class).

## Equipment for Weighing Aggregates

Scale sensitive to 0.10 lb., with capacity of 100 lb.
Containers to hold two aggregate batches.

## Equipment for Cleanup and Concrete Disposal

Large wheelbarrow for waste concrete.
Large washtank for cleaning equipment.
Stiff-fibered brushes with handles, for scrubbing equipment.

## Typical Concrete Mixes for Use in Tests (especially gravimetric test method)

| Mix 1, with 3/4-in. coarse aggreg. | | | Mix 2, with 1-1/2-in. coarse aggreg. | | |
|---|---|---|---|---|---|
| Materials | Wt., lb. | Abs. vol. cu. ft. | Materials | Wt., lb. | Abs. vol., cu. ft. |
| Cement Type IA | 30.65 | .156 | Cement Type IA | 30.65 | .156 |
| Water | 14.19 | .228 | Water | 12.96 | .208 |
| Fine agg., SSD | 78.16 | .473 | Fine agg., SSD | 65.77 | .398 |
| Cse. agg., SSD | 108.18 | .654 | Cse. agg., SSD | 127.90 | .774 |
| Totals | 231.2 | 1.511 | Totals | 237.3 | 1.536 |
| Unit weight, "No-air" (UWN) | $\frac{231.2}{1.511}$ = | 153.0 lb. per cu. ft. | Unit weight, "No-air" (UWN) | $\frac{237.3}{1.536}$ = | 154.5 lb. per cu. ft. |

The aggregates used in the two standard concrete mix designs shown above are from the same source and batched wet or dry.

At least one, probably two, machine-mixed concrete batches will be necessary for this laboratory session. If the determination of the air content by the gravimetric method is omitted, then any concrete mix will suffice for this session if it has an entrained air content. If the gravimetric method of determination is included in the session and the above mix designs are not practical, then the instructor will give the students a list of the concrete components with the absolute-volume data for each component.

## PREPARATION BEFORE LABORATORY SESSION

1. Draw water from the tap, preferably the day before the session, and store it in large containers so that it will be at room temperature and will contain a minimum of dissolved gasses.
2. Arrange to have the concrete mixes produced about 15 min. before testing. Laboratory assistants or students may assist in mixing.
3. Set out the required apparatus and ascertain that it is in operating condition. Check the operating condition of the air-meter gages, seals, and petcocks.

## WORK AFTER LABORATORY SESSION

1. Check the concrete-making equipment and meter parts for cleanliness and let them dry overnight before storing.
2. Check the washtanks for lost equipment.

## ASSIGNMENTS

In order to accomplish the performance of the tests in this session in the least amount of time using a minimal number of meters, it is advisable to assign certain tests to some groups, and other tests to other groups. Design two suitable mixes. One group, for example, might use concrete Mix 1 for the air pressure meter test, while another group uses concrete Mix 2 for the volumetric test. Then when both groups complete the tests, they may trade meters only, not concrete. This permits the students to compare the results of the various tests on the same concrete.

### Suggested Assignment for Test Result Comparison

| Group no. | Concrete mix design | Test nos. |
|---|---|---|
| 1 | Mix 1 | Tests 2, 4 |
| | Mix 2 | Tests 3, 5 |
| 2 | Mix 1 | Tests 3, 5 |
| | Mix 2 | Tests 2, 4 |

Time Allocation for Session (Rough Approximations)

| Procedure or method | Test no. | Min. time for test | Max. time for test |
|---|---|---|---|
| Calibration of pressure air meter (high-silhouette) | Demonstration by instructor | 40 min. | 60 min. |
| Calibration of pressure air meter (low-silhouette) | Demonstration by instructor | 20 min. | 30 min. |
| Agg. correction | 1 | 25 min. | 45 min. |
| Pressure air meter (high-silhouette) | 2 | 20 min. | 40 min. |
| Pressure air meter (low-silhouette) | 2 | 15 min. | 35 min. |
| Volumetric method | 3 | 10 min. | 30 min. |
| Gravimetric method | 4 | After class | After class |
| Air indicator | 5 | 10 min. | 20 min. |

**According to the above Time Allocation chart, the instructor will notice that it will probably not be possible to include all the tests. In that case, perform just those tests that the instructor deems most basic.**

## DEMONSTRATION BY INSTRUCTOR--PRESSURE AIR METER CALIBRATION

### Calibration of High-Silhouette Air Pressure Meter

The calibration of the high-silhouette pressure meter is completely described in ASTM C231. This procedure should be demonstrated at the beginning of the session and the calibration data given out for the students' use in the other tests. The manufacturer's instructions should be followed for use of the low-silhouette pressure meter.

## TEST 1-DETERMINATION OF AGGREGATE CORRECTION FACTOR

The aggregate correction factor determination is similar for both types of air pressure meter--high-or low-silhouette. The information given in Test 1, which is a part of ASTM C231, pertains specifically to the high-silhouette meter. The low-silhouette meter gives a determination of the "air content" of the inundated aggregate in the same way that the meter gives a determination of the air content of the concrete.

The aggregate correction factor varies with different aggregates. It also varies with the same aggregates having different moisture conditions. Dry aggregate, for example, has a comparatively large aggregate correction factor but when the same aggregate is wet, it has a low aggregate correction factor.

The sample of aggregate to be tested, a combination of fine and coarse aggregate, could be proportioned thus: two scoops of coarse to one scoop of fine aggregate.

It is important that the aggregate be thoroughly stirred in the air meter bowl. Two or three members of each group should take turns stirring.

## TEST 2-DETERMINATION OF AIR CONTENT OF PLASTIC CONCRETE BY AIR PRESSURE METER

One batch of machine-mixed concrete will provide enough concrete for at least four tests with a 1/4-cu. ft. capacity air meter.

If there is not sufficient time for the students to determine the aggregate correction factor or to witness a demonstration by the instructor, they should be furnished with the appropriate aggregate correction values in order to perform Test 2.

After step 1 of the procedure, the students may take a unit-weight test of the compacted concrete in the air meter bowl for use later on in the session (to determine the air content by gravimetric method).

If there is just one pressure air meter, and several groups are to make this test, it is advisable to fill the bowl iwth concrete just once. One group may fill and assemble the meter, then all the students in the groups may make one air content determination.

## TEST 3--DETERMINATION OF AIR CONTENT OF PLASTIC CONCRETE BY VOLUMETRIC METHOD

Caution the students about the danger of alcohol in the laboratory. Do not permit smoking near the alcohol.

## TEST 4--DETERMINATION OF AIR CONTENT OF PLASTIC CONCRETE BY GRAVIMETRIC METHOD

The students must determine or obtain from the intructor the hypothetical unit weight of the concrete, assuming it contained no air (UWN) and the actual unit weight of the concrete (UW), which may be determined during the pressure air-meter test.

This test may be calculated after the laboratory session if there is not enough time.

## QUESTIONS

1. Give a definition of air content percentage.

   Answer: The ratio, expressed as a percent, the volume of air to the total volume of the concrete.
2. What might be the reason that the Chace AE-55 is called an air indicator rather than an air meter?

   Answer: The air indicator does not measure as accurately as conventional air meter; and is not included as an air test instrument under most specifications.

3. Do the following equipment and/or methods require an aggregate correction factor? Why or why not?

High-silhouette type pressure air meter?

Answer: Yes, because it tests concrete, which contains aggregate.

Low-silhouette type pressure air meter?

Answer: Yes, because it tests concrete, which contains aggregate.

Roll-A-meter?

Answer: No, because volumetric devices indicate only the air in the paste, not the aggregate.

Chace AE-55 air indicator?

Answer: No, because the air in the aggregate is already accounted for in the specific gravity value. This method finds the voids in the paste.

Lab. No. 8

# DETERMINATION OF THE AIR CONTENT OF CONCRETE

## SESSION SCOPE

To become familiar with the current methods for determining the air content of concrete.

To perform the tests for determining the air content of concrete--using the pressure air meter, and the gravimetric and volumetric methods.

To learn the method of determining the aggregate correction factor.

## APPARATUS FOR SESSION

Mixing pans.
Concrete mixer, mechanical.
Cylindrical graduate, up to 25-ml. capacity, for measuring air-entraining admixture.
Scale sensitive to 0.01 lb. with minimum capacity of 20 lb.
Scale sensitive to 0.5 g., with 5-kg. capacity.
Tare bucket, plastic with pour spout, minimum capacity of 2-gal.
Tare scoop for weighing cement.
Scale sensitive to 0.10, with 100-lb. capacity, for weighing aggregates.
Containers to hold aggregates.
Trowels.
Cover plates.
High-silhouette or low-silhouette pressure air meter. (Figs. 1 and 3).
Roll-A-meter volumetric device, with auxiliary equipment. (Fig. 4).
Chace AE-55 air indicator with paper clip tampers, slotted spoons, etc. (Fig. 5).
Small plastic bottles for alcohol.

## MATERIALS FOR SESSION

Cement, sand, and gravel for the concrete batches to be tested.
Air-entraining agent.
Alcohol, methanol or isopropyl.
Water at room temperature.

## DEMONSTRATION BY INSTRUCTOR -PRESSURE AIR METER CALIBRATION

### CALIBRATION OF THE HIGH-SILHOUETTE PRESSURE AIR METER

Before the students perform the tests for the air content of concrete, the pressure air meter must be calibrated. The instructor will demonstrate the calibration methods, which are briefly explained below.

### APPARATUS

High-silhouette pressure air meter, with auxiliary equipment
Calibration cylinder, with volume equal to 3-6 percent of the volume of the meter measuring bowl.
Coil spring to hold the cylinder in place.
Cover plate.
Scale sensitive to 0.5 g.

### MATERIALS

Water at room temperature.

## PROCEDURE

1. Determine the weight of the water, w, in grams, required to fill the calibration cylinder.
2. Determine the weight of the water, W, in lb., required to fill the measuring bowl. Slide a glass plate over the bowl to ensure that the bowl is completely filled with water. Determine the volume of the measuring bowl, V, in cubic feet.
3. Determine the constant, R, which represents the volume of the calibration cylinder expressed as a percentage of the volume of the measuring bowl, calculating as follows:

$$R = 0.2205 \times \frac{w}{W}$$

4. Determine the expansion factor, D, for the air meter by filling the apparatus with water--making sure that all entrapped air is removed and that the water level is on the zero mark--and applying air pressure approximately equal to the operating pressure, P, which is determined by the method described in step 6 of this demonstration. The amount that the water column lowers will be the equivalent expansion factor, D, for that particular apparatus and pressure.
5. Determine the calibration factor, K, which is the amount that the water column must be depressed to obtain the gage pressure required to make the graduations on the glass tube correspond directly to the percentage of air introduced into the measuring bowl by the calibration cylinder when the bowl is level full of water. Calculate K as follows:

$$K = 0.98R + D$$

6. Invert the calibration cylinder and place it at the center of the dry bottom of the measuring bowl. Secure it against displacement by means of a spring acting against the top of the meter, and lower the conical cover. Clamp the cover in place and adjust the apparatus assembly to a vertical position. See Fig. 1.

   Add water by means of a tube and funnel, until it rises above the zero mark on the standpipe. Close the vent and pump air into the apparatus to the approximate operating pressure.

   Incline the assembly about 30 degrees from vertical and, using the bottom of the bowl as a pivot, describe several circles with the upper end of the standpipe, simultaneously tapping the cover and sides of the bowl lightly to remove entrapped air.

   Return the apparatus to a vertical position, gradually release the pressure, and open the vent. Bring the water level exactly to the zero mark by bleeding water through the petcock in the top of the conical cover.

   After closing the vent, apply pressure until the water level drops an amount equivalent to about 0.1 to 0.2 percent of air more than the value of the calibration factor, K. To relieve local restraints, lightly tap the sides of the bowl, and when the water level is exactly at the value of the calibration factor, K, read the pressure, P, indicated by the gage. Record the pressure to the nearest 0.1 psi.

**Gradually release the pressure and open the vent to determine whether the water level returns to the zero mark when the sides of the bowl are tapped lightly. If the water level fails to return to within 0.05 percent of the zero mark and no leakage beyond a few drops of water is found, some air probably was lost from the calibration cylinder.**

**In this case, repeat the calibration procedure from the beginning of this section, step 6. Check the indicated pressure reading promptly by bringing the water level exactly to the zero mark, closing the vent, and applying the pressure, P, just determined.**

**Tap the gage lightly with your finger. When the gage indicates the exact pressure, P, the water column should read the value of the calibration factor, K, used in the first pressure application within about 0.05 percent.**

## CALIBRATION OF LOW-SILHOUETTE PRESSURE AIR METER

### APPARATUS

**Low-silhouette pressure air meter, with auxiliary equipment.**
**Scale sensitive to 0.5 g.**

### MATERIALS

**Water at room temperature.**

### PROCEDURE

**A typical calibration of the low-silhouette air pressure meter would include these basic steps.**

1. **Fill the base container with water. Clamp on the cover.**
2. **If the apparatus uses only a small amount of water, add the proper amount of water.**

3. Close the valves to the air chamber. Pump air into the chamber to slightly more than the initial pressure mark. Allow the air to cool for a few seconds. Bleed the chamber to the initial operating pressure mark while tapping the gage lightly.
4. Open the operating valve (which allows air to go from the air chamber to the container), allowing the air to warm for a few seconds while tapping the gage lightly. The indicated air content should be 0 percent.
5. Repeat steps 1 to 4, drawing off successive increments of water into the calibration cylinder or measure before each measurement in accordance with the manufacturer's instructions.

   The indicated air content should be that represented by the amount of water removed from the meter.
6. If the indicated air content does not equal the correct amount, the equipment should be adjusted by changing the initial line, by remarking the dial of the pressure gage, by shifting the dial of the pressure gage, or by adjusting the pressure gage.

## TEST 1-DETERMINATION OF AGGREGATE CORRECTION FACTOR

### SCOPE

To determine the aggregate correction factor in order to use air pressure meters, using ASTM C231.

### APPARATUS

Measuring bowl, with cover that ensures pressure-tight assembly.
Tamping rod, soft-tipped.
Mallet with a rubber or rawhide head or wooden 2x2 billet.
Syringe or alcohol spray.

### MATERIALS

Combined sample of fine and coarse aggregate is representative of aggregate used in concrete batches for the tests.

## PROCEDURE

### Related Information

**Because the pores in aggregates contain a mixture of water and air, an aggregate correction factor must be determined in order to make a proper calculation of the air content in concrete using the high-silhouette air pressure meter. During the performance of the pressure meter test, the air in the aggregates is compressed. The compression effects of the aggregate's pore air must be determined separately from the compression effects of the intentionally entrained air in the concrete, because entrained air occurs only as voids in the paste.**

1. **Calculate the weights of fine and coarse aggregate present in the volume, S, of the sample of fresh concrete the air content of which is to be determined as follows:**

$$Fs = \frac{S}{B} \times Fb$$

$$Cs = \frac{S}{B} \times Cb$$

**where: Fs = weight, in pounds, of fine aggregate in concrete sample under test;**

**S = volume, in cubic feet, of concrete sample (same as volume of measuring bowl of apparatus);**

**B = volume, in cubic feet, of concrete produced per batch.**

$$B = \frac{(N \times 94) + Fb + Cb + Ww}{W}$$

**where B = volume, in cubic feet, of concrete produced per batch;**

**N = number of bags of cement in the batch;**

**94 = net weight, in pounds, of a bag of cement;**

**Fb = total weight, in pounds, of fine aggregate in batch in condition used.**

**Cb = total weight, in pounds, of coarse aggregate in batch in condition used;**

**Ww = total weight, in pounds, of mixing water added to batch.**

**F b = total weight, in pounds, of fine aggregate in the condition used in batch;**

**Cs = weight, in pounds, of coarse aggregate in concrete sample under test;**

**Cb = total weight, in pounds, of coarse aggregate in the condition used in batch.**

2. Mix representative samples of fine aggregate (of weight Fs) and coarse aggregate (of weight Cs), and add gradually to the measuring bowl filled one-third full of water until all the aggregate is covered with water. Add the aggregate by the scoopful, pouring slowly so as little air as possible will be entrapped. To eliminate air, after each addition of aggregate, tap the sides of the bowl. Lightly rod the upper inch of the aggregate about 10 times and stir the aggregate well. Promptly remove accumulations of foam.
3. When the aggregate has been inundated for a period of time equal to the time between the introduction of water into the concrete mixer and the time of performing the test for air content, strike off all foam and excess water. Clean the flanges of the bowl and the conical cover, so that when the cover is clamped in place a pressure tight seal will be obtained. Complete the test as described in Test 2, steps 3, 4, and 5 for the particular type of pressure meter used.
4. The aggregate correction factor, G, is equal to $h_1 - h_2$ as determined in the tests on the aggregate.

## TEST 2-DETERMINATION OF AIR CONTENT OF PLASTIC CONCRETE BY PRESSURE METER

### SCOPE

To determine the air contant of freshly mixed concrete from observations of the change in volume occurring with a change in pressure, using ASTM C231.

### APPARATUS

Pressure air meters with auxiliary equipment--high-silhouette (Figs. 1 and 2) or low-silhouette types. (Fig. 3).
Tamping rod, soft-tipped.
Mixing pan.
Two trowels.
Cover plate.
Mallet with rubber or rawhide head, or wooden 2x2 billet.
Strikeoff bar.
Syringe or alcohol spray.

## MATERIALS

Freshly mixed concrete, mixed by instructor in mechanical mixer.

Pressure meters operate by subjecting the concrete in the bowl to external pressures and measuring the pressure changes in the concrete. These meters give a direct reading of the air content of the concrete compacted in the bowl.

The high-silhouette pressure air meter measures the air content of the concrete as a change in the volume of the concrete in response to a change in pressure inside the meter. See Fig. 2.

The low-silhouette pressure air meter measures the air content of the concrete as a function of the change in pressure that occurs as a small amount of compressed air is jetted into the meter. See Fig. 3.

## PROCEDURE

### High-Silhouette Pressure Air Meter (ASTM C231)

1. Fill the measuring bowl in three equal layers, consolidating each layer by rodding it 25 times with the tamping rod furnished with the meter. In rodding the second and third layers, only enough force should be used to penetrate the surface of the previous layer. After each layer is rodded, tap the bowl with a rawhide or rubber mallet or with a 2x2 wooden billet, about 10 times. Slightly overfill the bowl with the third layer and after rodding, remove the excess concrete by sliding the strikeoff bar across the top flange with a sawing motion until the bowl is just level full. *
2. Thoroughly clean the flanges of the bowl and of the conical cover so that when the cover is clamped in place a pressure tight seal will be obtained. Small particles lodging between the bowl and the rubber seal can cause leaks as pressure is applied.
3. Assemble the apparatus and clamp the cover on tightly. Add water over the concrete through the tube until the water rises to about the halfway mark in the standpipe. Incline the apparatus assembly about 30° from vertical. Using the bottom of the bowl as a pivot describe several circles with the upper end of the column, while simultaneously tapping the sides of the bowl. Remove foam from the surface of the water column with a syringe or with a spray of alcohol. Bring the water level to the zero mark of the graduated tube before closing the vent at the top of the water column. See Fig. 2(A).

*Weigh the leveled-off concrete in the bowl to use for a unit-weight reading for Test 4.

4. Apply about 0.2 psi more than the desired test pressure, P, to the concrete by means of the small hand pump. (The instructor will furnish the operating pressure of the air meter and other calibration factors, except for the aggregate correction factor, which the students calculate in Test 1.)

   To relieve local restraints, tap the sides of the bowl. When the pressure gage indicates the exact test pressure, P, read the water level, $h_1$, and record it to the nearest 0.10 or 0.05 percent air content on the graduated precision bore tube or gage glass of the standpipe. See Fig. 2(B).

   For extremely harsh mixes, it may be necessary to tap the bowl vigorously until there is no change in the indicated air content.

   Gradually release the air pressure through the vent at the top of the water column and tap the sides of the bowl lightly for about 1 min. Record the water level, $h_2$, to the nearest division or half division (0.10 or 0.05 percent air content). See Fig. 2(C). The apparent air content, $A_1$, is equal to $h_1 - h_2$.

5. Repeat the steps described in step 4, but without adding water to bring the water level back to the zero mark. Check the two consecutive determinations of the apparent air content and average them to give the value, $A_1$, to be used in calculating the air content. The two determinations should be within 0.2 percent of each other.

   Calculate the air content of the concrete as follows:

$$A = A_1 - G$$

where A = air content, percentage by volume of concrete.

A = apparent air content, percentage by volume of concrete

G = aggregate correction factor, percentage by volume of concrete, obtained from Test 1.

## Low-Silhouette Pressure Air Meter

Since there are so many low-silhouette type air meters, and each has different methods of use, the manufacturer's instructions for each particular meter should be followed. The instructions given here are the basic procedure.

1. Fill the concrete bowl with concrete. Strike off the surface level with the top surface of the bowl. *
2. Assemble the meter with all the petcocks open except the one connecting the pressure chamber and the concrete bowl.
3. Thoroughly fill the air-filled space at the top of the concrete bowl with water by pouring water through one of the petcocks directly connecting the bowl with the atmosphere.

*Weigh the leveled-off concrete in the bowl to use for a unit-weight reading for Test 4.

4. **Close all the petcocks to the pressure chamber and pump up the pressure to the required starting pressure. Then close the water-purging stopcocks to the concrete bowl.**

   **Then quickly open the petcock between the pressure chamber and the concrete bowl. Note the air content reading on the pressure dial as soon as it comes to rest. This is the "gross air content" of the mix.**
5. **From the gross air content of the concrete (the air in the paste plus the compressibility effects of air in the aggregate pores) deduct the aggregate correction factor to obtain the net air content of the concrete, which is the specification value for air content.**

## TEST 3--DETERMINATION OF THE AIR CONTENT OF PLASTIC CONCRETE BY VOLUMETRIC METHOD

### SCOPE

**To determine the air content of freshly mixed concrete containing aggregate of any kind (dense, cellular, or lightweight), by means of volumetric air meter, using ASTM C173.**

### APPARATUS

**Volumetric air meter (Roll-A-meter).**
**Metal funnel**
**Tamping rod, soft-tipped.**
**Strikeoff bar.**
**Metal measuring cup, with capacity equal to 1.0 percent of the volume of the bowl of the bowl of the air meter.**
**Rubber syringe with a capacity at least as large as the measuring cup.**
**Metal or glass container of about 1-qt. capacity.**
**Trowel.**
**Scoop.**

### MATERIALS

**Freshly mixed concrete.**
**Isopropyl alcohol.**
**Water room temperature.**

PROCEDURE

Precautions: This tests makes use of alcohol to dispel the foam that rises to the top of the air meter charge. No smoking will be allowed while this test is being performed. Take care to record the number of one-cup additions of alcohol used in the test.

1. Fill the bowl with freshly mixed concrete in three layers of equal depth, using the scoop and trowel. Rod each layer 25 times with the tamping rod, and tap the sides of the bowl 10 to 15 times after each rodding.
2. After the third layer of concrete is placed in the bowl, strike off the excess concrete with the strikeoff bar until the surface is flush with the top of the bowl. Wipe the flange of the bowl clean.
3. Clamp the top on the bowl. Insert the funnel in the top, and add water until it is visible in the neck of the top. Remove the funnel and adjust the water level by means of the rubber syringe until the bottom of the meniscus is level with the zero mark. Attach and tighten the screw cap. See Fig. 4.
4. Invert and agitate the apparatus until the concrete is mixed thoroughly with the water and no concrete remains settled at the bottom of the bowl. Then, holding the neck of the apparatus elevated, roll the apparatus (at least three minutes) until no further drop in the water column is observed. This means that all the air has been removed from the concrete and allowed to rise to the top of the apparatus.
5. Remove the screw cap. Add sufficient isopropyl alcohol--in one-cup increments to dispel the foam on the surface of the water.
6. Read the liquid at the bottom of the meniscus in the neck of the apparatus including the amount of alcohol added. Estimate to the nearest 0.1 percent and record the reading on the laboratory data sheet for this test.
7. Empty the bowl, clean it, and dry it well.

## TEST 4-DETERMINATION OF THE AIR CONTENT OF PLASTIC CONCRETE BY GRAVIMETRIC METHOD

SCOPE

To determine the air content of freshly mixed concrete using the gravimetric method.

## APPARATUS

**Air meter bowl or unit-weight measure.**

## MATERIALS

**Freshly mixed concrete in the bowl, from Test 2.**

## PROCEDURE

1. **Using the air meter bowl from Test 2 (or a unit-weight measure), weigh the bowl and the air-entrained concrete in it. Empty the bowl, clean and dry it, and weigh again. Determine the weight of the air-entrained concrete that was in the bowl.**
2. **Calculate the volume of the meter bowl. Calculate the unit weight of the concrete (UW).**
3. **Using information from the instructor on the concrete mix design, calculate the hypothetical unit weight of the concrete if it contains no air (UWN), as shown in the examples below. When these two unit weights are known, calculate the gravimetric air content in this manner:**

$$\text{Gravimetric air content} = \frac{\text{UWN} - \text{UW}}{\text{UWN}} \times 100 = \underline{\qquad}\%$$

4. **Compare the gravimetric air content percentage with the pressure meter air content percentage of the same concrete.**

Examples of Hypothetical Concrete Mix Designs to Determine UWN

| Mix 1, with 3/4-in. coarse aggreg. | | | Mix 2, with 1-1/2-in. coarse aggreg. | | |
|---|---|---|---|---|---|
| Materials | Wt., lb. | Abs. vol., cu. ft. | Materials | Wt., lb. | Abs. vol., cu. ft. |
| Cement Type IA | 30.65 | .156 | Cement Type IA | 30.65 | .156 |
| Water | 14.19 | .228 | Water | 12.96 | .208 |
| Fine agg. SSD | 78.16 | .473 | Fine agg. SSD | 65.77 | .398 |
| Cse. agg. SSD | 108.18 | .654 | Cse. agg. SSD | 127.90 | .774 |
| Totals | 231.2 | 1.511 | Totals | 237.3 | 1.536 |
| Unit weight "No-air" (UWN) | $\frac{231.2}{1.511}$ | = 153.0 lb. per cu. ft. | Unit weight "No-air" (UWN) | $\frac{237.3}{1.536}$ | = 154.5 lb. per cu. ft. |

## TEST 5-DETERMINATION OF THE AIR CONTENT OF PLASTIC CONCRETE BY AIR INDICATOR

### SCOPE

**To determine the air content of freshly mixed concrete by an approximate method, testing only the mortar of the concrete. (This test is a field test, using the volumetric method.)**

### APPARATUS

**Air indicator (Chace AE-55), made of glass, with a rubber stoper.**
**Tamper, made from a paper clip.**
**Mortar conversion table.**
**Metal Funnel.**
**Slotted spoon.**

## MATERIALS

Alcohol.
Freshly mixed concrete.

## PROCEDURE

1. Scrape mortar from a representative sample of concrete by means of a slotted spoon or a knife blade, eliminating all aggregate larger than 1/8-in. in diameter. Place the mortar in the thimble-sized sample container. See Fig. 5 (A-D).
2. Rod the mortar in three lifts, using a paper clip. Strike off the top of the sample container into the bottom of the indicator, adding or removing alcohol so that the liquid level is at zero. See Fig. 5 (E-H).
4. Keep the thumb on the top of the indicator and shake it vigorously until the contents are a slurry and all air bubbles rise to the top of the indicator. See Fig. 5 (I).
5. Do not disturb the stopper in any way, or the test will be invalid. Count the number of marks the liquid level has declined down from the zero mark. Use the Mortar Conversion Table on the laboratory data sheet for this test to determine the actual air content of the concrete. See Fig. 5 (J).

## Care of Apparatus

Since most new air meters are made of aluminum or magnesium alloys, they are lightweight, and resistant to rust. They do, however, need special care and maintainance. The following are some precautions to observe in the use of air meters:

1. Ordinary steel tamping rods could ruin the airtight seal of the apparatus by making dents in the rims of the bowls. Use the special soft-tipped tampers that come with the apparatus. If no such tampers are available, make them from 5/8-in. wooden dowl stock (presoaked in boiled linseed oil to eliminate water absorption).
2. Take care to dry the apparatus well after washing to prevent corrosion. Do not assemble the apparatus after the session, because it needs more time to dry out completely.
3. Clean the rim of the concrete bowl and the rubber seal in the top of the meter so that no particles can disturb the meter seal. The particles may make a slight difference in the air contents to be determined.
4. Do not interchange air meter bowls, as this can make the calibrations invalid.

5. When making the air meter determinations, the aggregate correction factor, and the meter calibrations, keep the meter inside a mixing pan to prevent flooding when emptying the apparatus at the end of the test.

## REPORT

1. Make the calculations for the tests using the laboratory data sheets provided.
2. The notekeeper of each group will report his group's findings to the instructor as soon as all the assigned tests are completed.
3. Make comparisons between the values obtained by the different methods of testing air content. Compare the findings on the same tests using the different concrete mixes.

## QUESTIONS

1. Give a definition of air content percentage.
2. What might be the reason that the Chace AE-55 is called an air indicator rather than an air meter?
3. Do the following equipment and/or methods require an aggregate correction factor? Why or why not?

High-silhouette type pressure air meter?
Low-silhouette type pressure air meter?
Roll-A-meter?
Chace AE-55 air indicator?
Gravimetric air determination method?

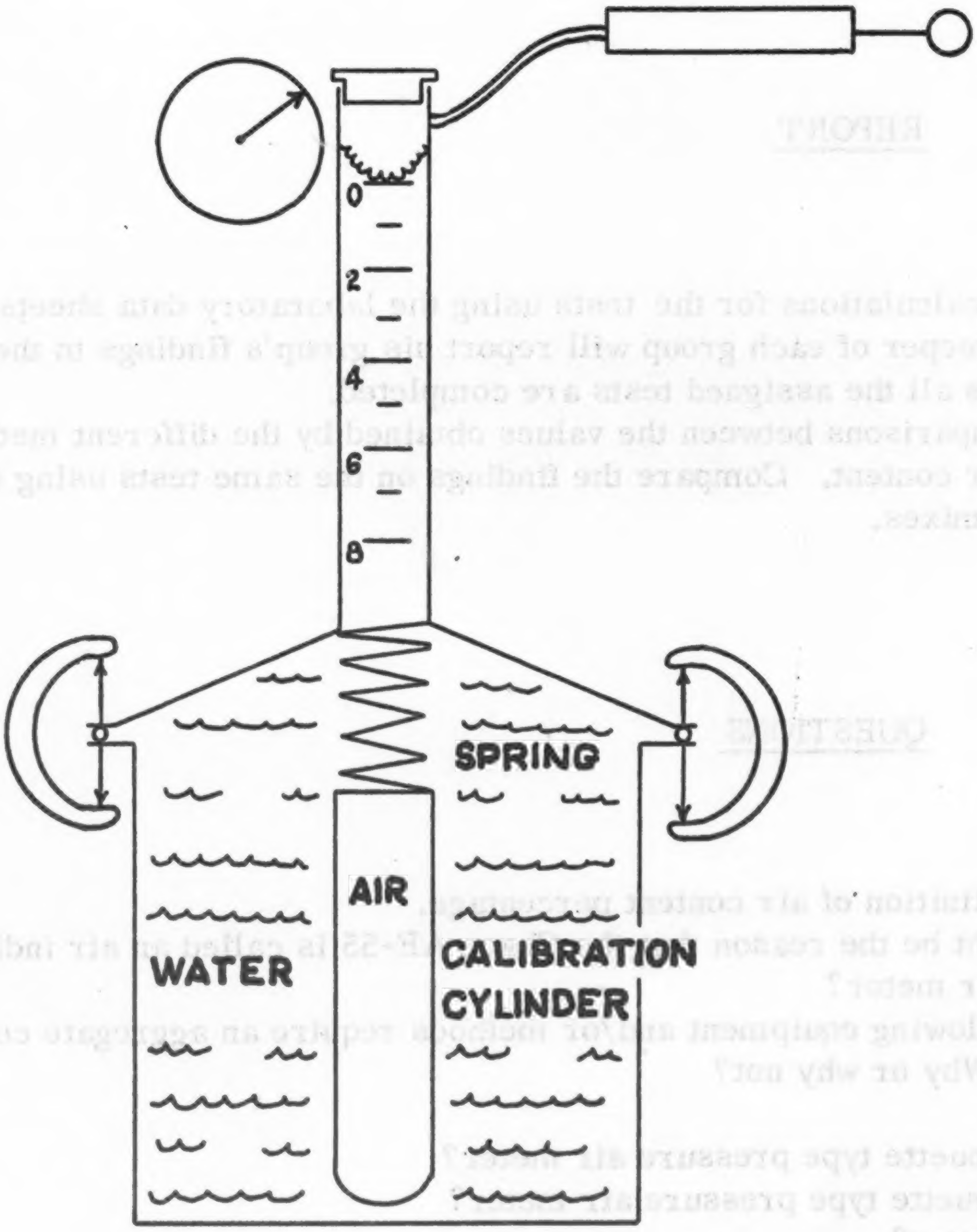

0
2
4
6
8
SPRING
AIR
WATER
CALIBRATION
CYLINDER

Fig. 1--"High-silhouette" air pressure meter. Calibration setup.

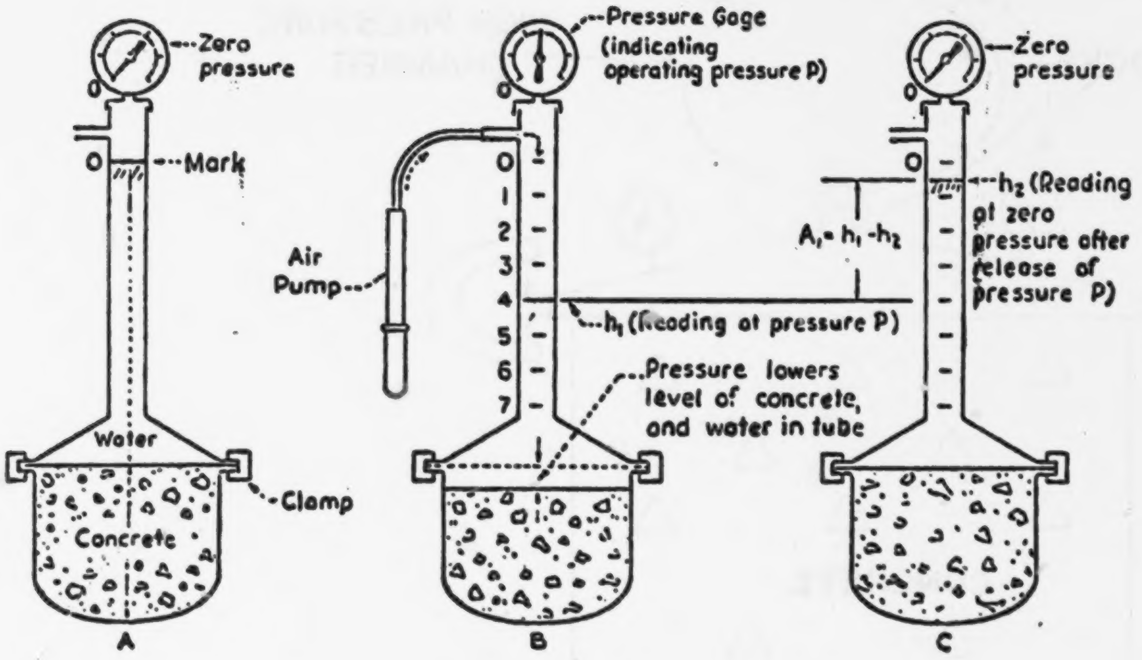

Zero pressure
0
0
Mark
Water
Clamp
Concrete
A
Pressure Gage (indicating operating pressure P)
0
0
1
2
3
4
5
6
7
Air Pump
h₁ (Reading at pressure P)
Pressure lowers level of concrete, and water in tube
B
Zero pressure
0
0
A₁= h₁ -h₂
h₂ (Reading at zero pressure after release of pressure P)
C

*Fig. 2--Pressure method of test for air content.

*taken from ASTM, Part 10, 1966 edition.

√

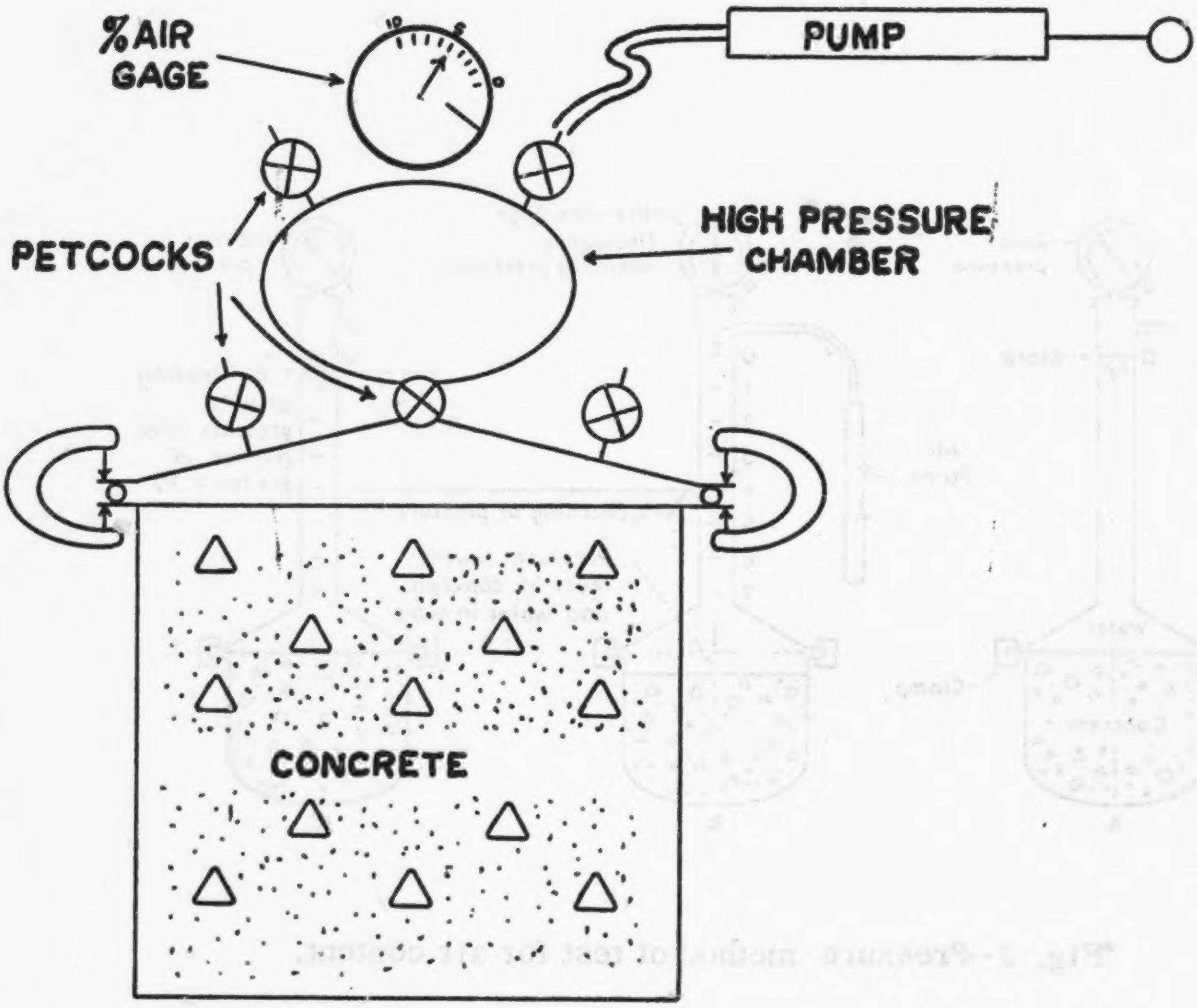

%AIR GAGE
PUMP
HIGH PRESSURE CHAMBER
PETCOCKS
CONCRETE
10
5
0

Fig. 3--"Low-silhouette" air pressure meter.

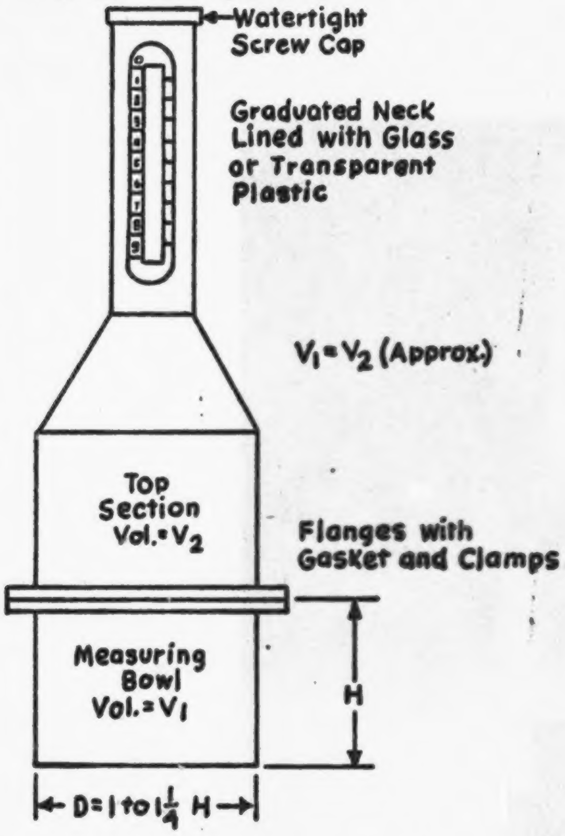

Watertight Screw Cap
Graduated Neck Lined with Glass or Transparent Plastic
$V_1 = V_2$ (Approx.)
Top Section Vol. = $V_2$
Flanges with Gasket and Clamps
Measuring Bowl Vol. = $V_1$
H
D = 1 to $1\frac{1}{4}$ H

Fig. 4--Volumetric air meter.

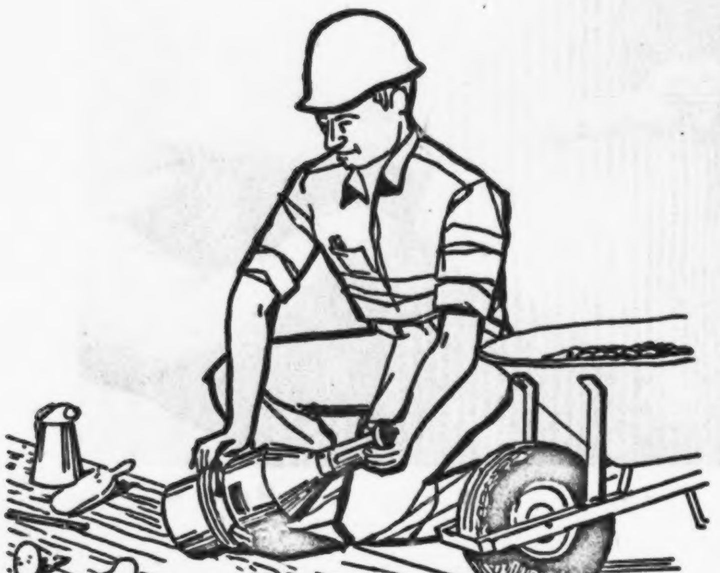
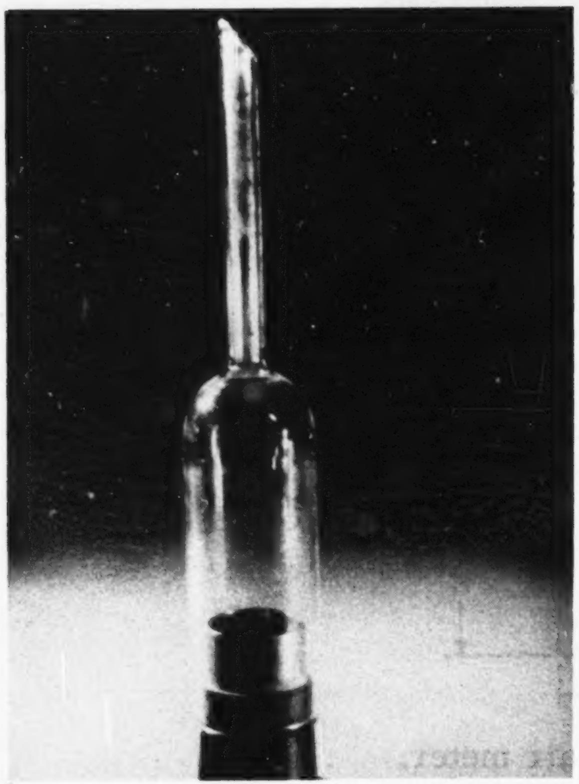
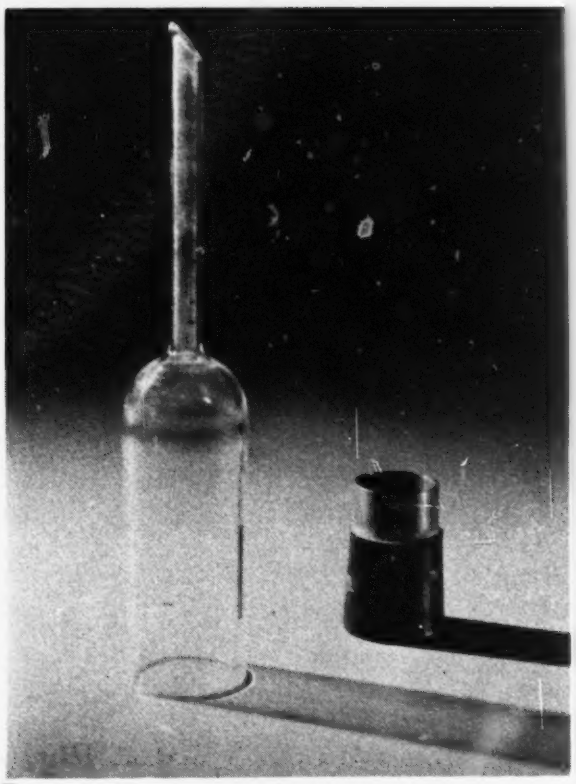


Fig. 4a. The volumetric method can be used with concretes made with any type of aggregates. It is especially recommended for lightweight or cellular concretes.

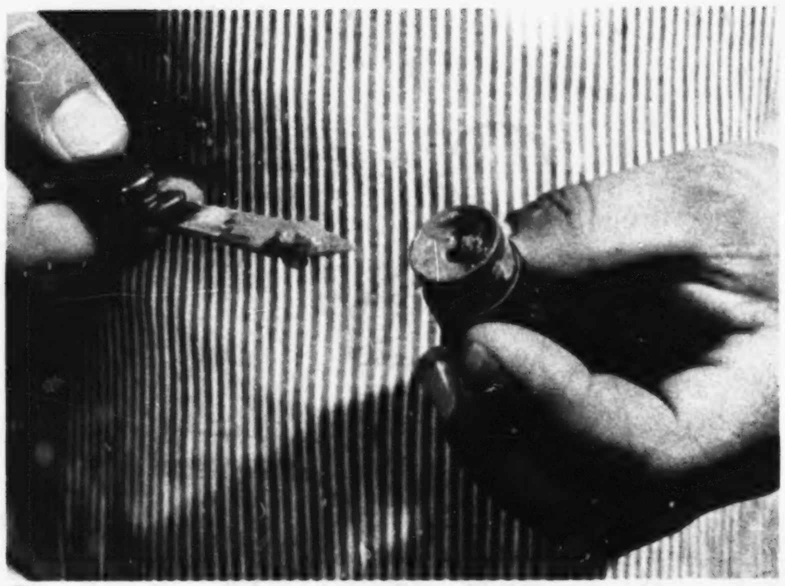
# THE CHACE AE-55 AIR INDICATOR



A

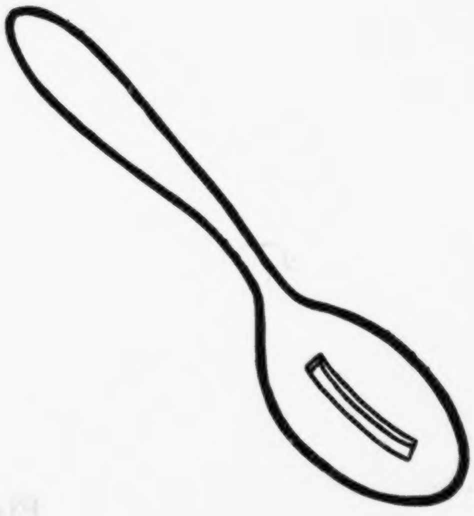


B

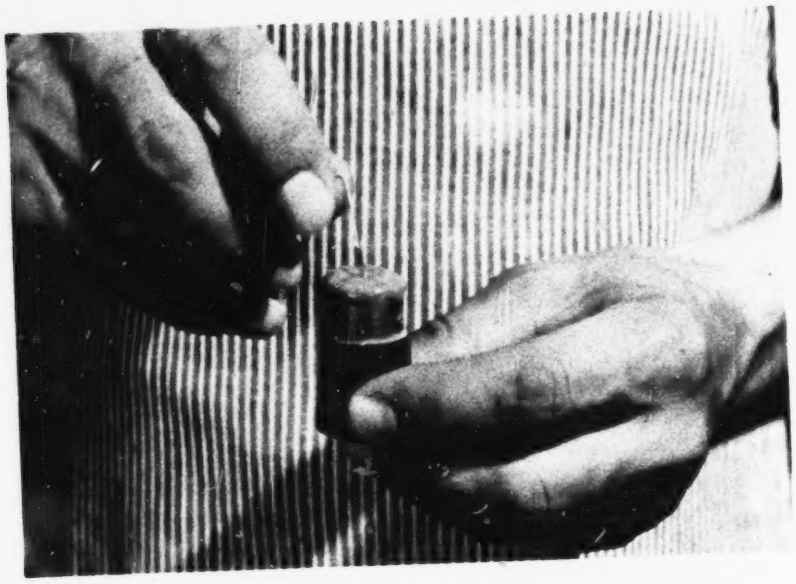


C

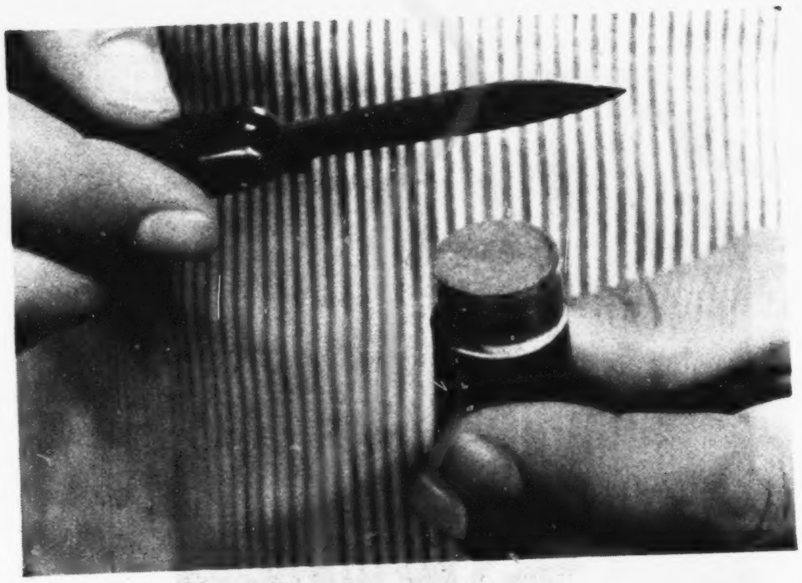
**Note: Suitable slot widths may be obtained by cutting the slot with two hacksaw blades ganged side by side or by using a 4-in. mill bastard file on edge.**



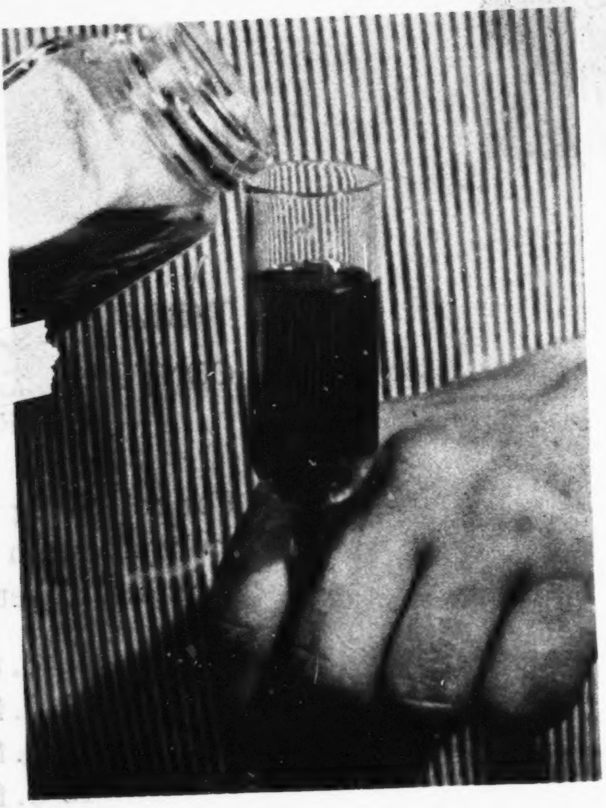
D **Sample - splitting teaspoon**



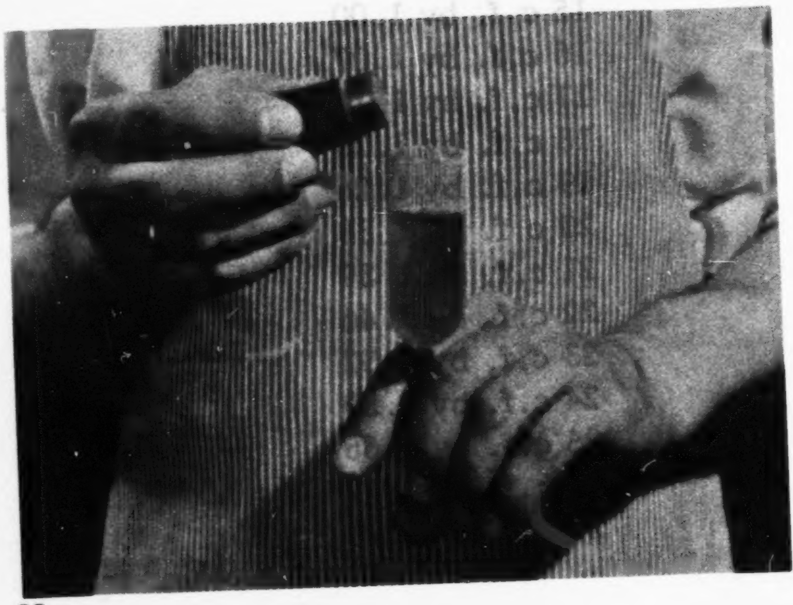
E



F

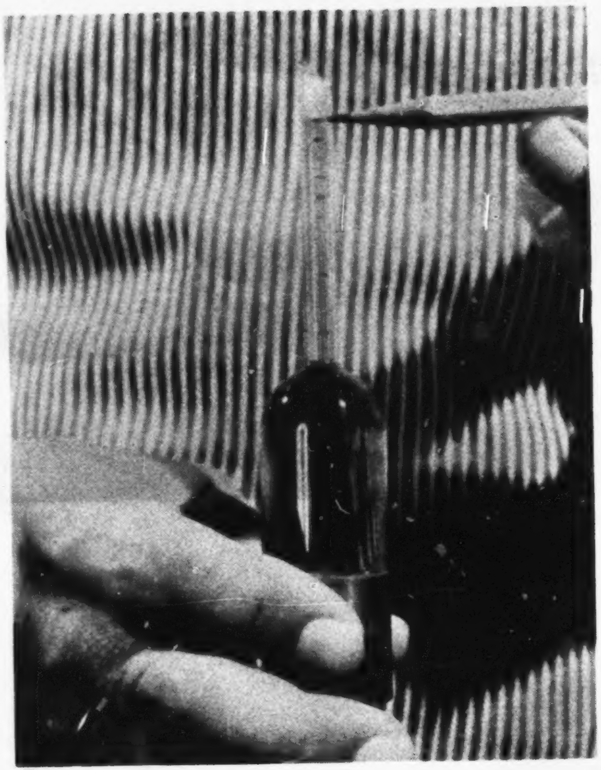


G



H

I



J

TABLE 2

### CONVERSION TABLE FOR CHACE AIR INDICATOR

**For following mortar content per cu. yd. multiply stem reading by appropriate constant to get percent air:**

**10 c.f. by 0.67**
**11 c.f. by 0.73**
**12 c.f. by 0.80**
**13 c.f. by 0.86**
**14 c.f. by 0.93**
**15 c.f. by 1.00**
**16 c.f. by 1.07**
**17 c.f. by 1.13**
**18 c.f. by 1.20**
**19 c.f. by 1.26**
**20 c.f. by 1.33**
**21 c.f. by 1.39**
**22 c.f. by 1.46**
**23 c.f. by 1.52**
**24 c.f. by 1.59**
**25 c.f. by 1.66**
**26 c.f. by 1.72**
**27 c.f. by 1.78**

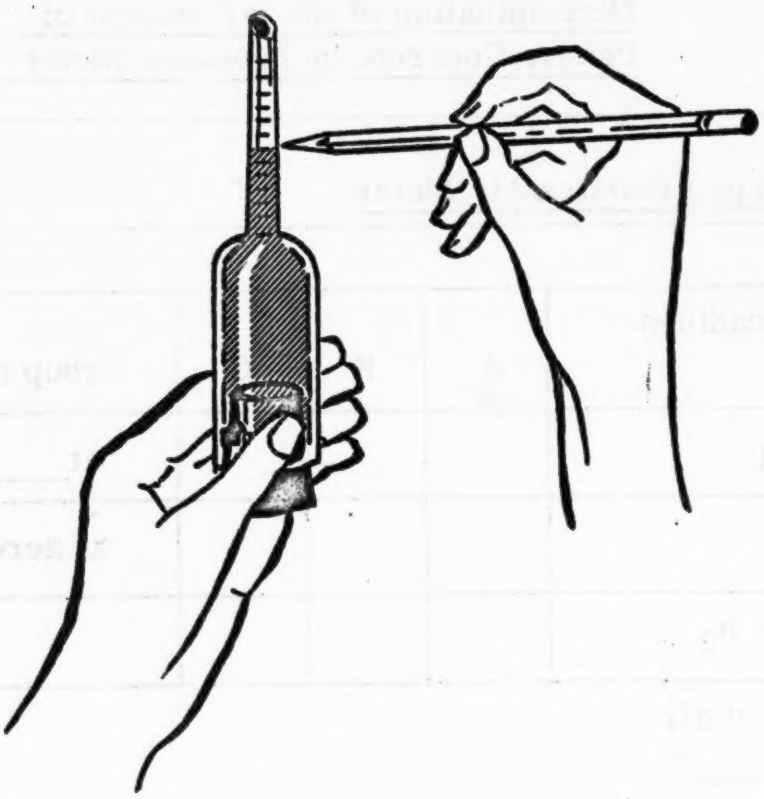


Fig. 5--Chace AE-55 air indicator.

## DATA SHEET FOR TEST 2

### Determination of the air content of Plastic Concrete by Pressure Meter

**High-Silhouette Type Pressure Air Meter**

| | | | | |
|---|---|---|---|---|
| Pressure meter readings operator | A | B | C | Group no. ____ Meter no. ____ |
| Initial reading, $h_1$ | | | | at ______ psi gage pressure. |
| Lag reading, $h_2$ | | | | at zero pressure. |
| Apparent air, $h_1 - h_2$ | | | | |

Average of apparent air by A, B, C. _____%

Aggregate correction factor __________%

Net air content of concrete = averaged apparent air minus agg. cor. factor
__________ - ____________=net air content.

**Low-Silhouette Type Pressure Air Meter**

| | | | | |
|---|---|---|---|---|
| Pressure meter readings operator | A | B | C | Group no. ____ Meter no. ____ |
| Apparent air | | | | % at initial index mark ____ |

Average of apparent air by A, B, C. ________%

Aggregate correction factor _______________%

Net air content of concrete = averaged apparent air minus agg. cor. factor.
__________-____________=net air content

## DATA SHEET FOR TEST 3

### Determination of the Air Content of Plastic Concrete by Volumetric Method--Roll-A-Meter

Group no. ________________ Meter no. ______________

Number of cups of alcohol needed to dispel foam ______________(a)

Air meter reading when foam is dispelled ______________(b)

Net air content of concrete = (a) + (b) = ______________(%)

## DATA SHEET FOR TEST 4

### Determination of the Air Content of Plastic Concrete by Gravimetric Method

Group no. Meter no. Mix no.

Weight of meter bowl filled with air-entrained concrete lb.

Weight of meter bowl lb.

Weight of air-entrained concrete lb.

Volume of meter bowl cu. ft.

Unit weight of air-entrained concrete (UW) = $\frac{(A)}{(B)}$ = lb. per cu. ft.

Gravimetric air content = $\frac{UWN - UW}{UWN}$ X 100 %

# DATA SHEET FOR TEST 5

## Determination of the Air Content of Plastic Concrete by the Air Indicator

### Chace AE-55 Air Indicator

| | |
|---|---|
| **Group no.** | **Concrete mix no.** |

Absolute volume of water in 1 cu. yd. of concrete ____________________ (A)

Absolute volume of cement in 1 cu. yd. of concrete ____________________ (B)

Absolute volume of fine aggregate in 1 cu. yd. of concrete ____________________ (C)

Concrete mortar content (A) = (B) = (C) = ____________________ (D)

Mortar factor = $\frac{(D)\ X\ 27}{15}$ = ______________ (E)

The Chace AE-55 air indicator is calibrated to give the correct air percentage for a concrete mix containing 15 cu. ft. of mortar per cu. yd. of concrete.

Percentage of entrained air= Indicator reading X (E) = __________ %

### Mortar Conversion Table

| Concrete mortar content, cu. ft. per cu. yd. | Mortar factor (E) |
|---|---|
| 10 | 0.7 |
| 12 | 0.8 |
| 14 | 0.95 |
| 16 | 1.1 |
| 18 | 1.2 |
| 20 | 1.3 |
| 22 | 1.5 |
| 24 | 1.6 |
| 26 | 1.7 |

PRINCIPLES OF CONCRETE Unit 2, Session 16
Air-Entrained Concrete

## GENERAL OBJECTIVE

To develop an understanding of air-entrained concrete, how it's obtained, and its principal benefits.

## PERFORMANCE OBJECTIVES

The student should be able to give reasons for using intentionally entrained air in concrete.

The student should be able to explain the effects of entrained air on the properties of fresh concrete.

The student should be able to explain how and why air entrainment affects workability.

The student should be able to describe the two methods used to obtain air entrainment in concrete.

## INTRODUCTION

In the mid 1930's air-entrained concrete was developed and tested. The people in the concrete industries look upon this discovery as one of the greatest advances in concrete technology. Today the use of entrained air is recommended in concrete for nearly all purposes.

The principal reason for using intentionally entrained air is to improve concrete's resistance to freezing and thawing exposure. However, there are other important beneficial effects of entrained air in both plastic and hardened concrete.

Air-entrained concrete is produced by using either an air-entraining cement or an air-entraining admixture during the mixing of concrete.

## OVERVIEW OF SESSION

**In this session the instructor will need to discuss the development of air-entrained concrete and the testing that established the validity of laboratory findings. Also, this session will cover the effects of air entrainment on the concrete mix and hardened concrete.**

## SESSION OUTLINE

**I. History**
  **A. Mid 1930's**
  **B. Laboratory research**

**II. Explanation**
  **A. Definition**
  **B. Uses**
  **C. Benefit**
  **D. How produced**
  **E. Advantages of types**

**III. Effects on Fresh Concrete**
  **A. Less water**
  **B. Improved workability**
  **C. Less segregation and bleeding**
  **D. Earlier finishing**
  **E. Finishing differences**
  **F. Variability-control**

**IV. Effects on Hardened Concrete**
  **A. Freeze-thaw resistance**
  **B. Resistance to scaling**
  **C. Improved watertightness**
  **D. Strength loss**

## RELATED ACTIVITIES

1. **Make a comparison of the properties of air-entrained cement and non-air-entrained cement.**
2. **Make a slump test using air-entrained and non-air-entrained concretes.**
3. **Observe differences in workability.**

## TOOLS AND MATERIALS

### ILLUSTRATIONS

Air-Entrained Concrete, (IS 045.02T), from PCA.

### SLIDES

IV-F "Effect of Air-Entrainment on Resistance of Concrete," from PCA Quality Concrete Slide Reference File.

IV-F-6 Comparison of air-entrained and non-air-entrained concrete at Naperville, Ill., test plot.

IV-F-1 through IV-F-5 Examples of concrete with and without air-entrainment.

Note to Instructor: See Index to Quality Concrete Slide Reference File for complete listing of slides on this subject.

| Presentation Outline | Teaching Techniques, Aids & Devices |
|---|---|
| I. History of Air Entrainment<br>A. Air entrainment for concrete discovered in the mid 1930's<br>B. Tests showed improved characteristics | |
| II. Explanation<br>A. Definition<br>B. Uses: Recommended for nearly all purposes<br>C. Principal benefit: Improves the material's resistance to surface deterioration resulting from freezing and thawing<br>D. How produced<br>1. Using air-entrained cement<br>2. Adding air-entraining agent during mixing<br>E. Advantages of each type | Refer to Fig. 1, have transparency made of figure . . . or use PCA slide IV-F.<br>Slide IV-F-6 from PCA. |
| III. Effects of Air Entrainment on Plastic Concrete<br>A. Lower water requirement<br>B. Easier to place and finish<br>C. Less segregation and bleeding<br>D. Less water and sand required. Both water and sand proportions must be adjusted to maintain the same strength. The water content will be 3- to 5 gal. less per cu. yd. compared with concrete with no air entrainment and with the same slump. A 3-6 percent reduction in sand is possible. | |
| IV. Effects of Air Entrainment on Hardened Concrete<br>A. Greatly improved resistance to repeated freezing and thawing while saturated with water<br>B. Effective in preventing serious surface scaling caused by de-icing chemicals<br>C. Far more watertight than concrete without entrained air | PCA slides IV-F-1 through IV-F-5. |

# RELATED INFORMATION

## HISTORY

**As early as 1932, it was discovered that improved workability and plasticity of concrete resluted from the inclusion of semi-microscopic bubbles of air. This air lubricates the mix, permitting substantial reductions in mixing water and better placeability of the concrete.**

**Subsequent tests showed this concrete to be extremely durable, particularly when subjected to freezing and thawing in the presence of water and salt solutions. Early experiments also showed that the entrained air almost eliminated segregation and bleeding of the concrete and produced a substantial increase in the workability characteristics of the mix.**

## EXPLANATION

**Air entraining is defined as the capability of a material or process to develop a system of minute bubbles of air in cement paste, mortar or concrete.**

**During normal mixing action a small amount of air is always entrapped in a mix. This is derived from air present in aggregates and cement, from air dissolved in mixing water, and from air brought in by mechanical action of the mixer. Air from these sources is neither stable nor useful because the bubbles are relatively large, widely separated and of irregular shape.**

**Unlike entrapped air, intentionally entrained air is in the form of minute, disconnected bubbles having diameters measured in thousandths of an inch, closely spaced, and well distributed throughout the paste.**

**Microscopic examinations of hardened concrete indicate that as many as 400 to 600 billion bubbles are entrained in a single cu. yd. of concrete having an air content in the range of 3- to 6 percent by volume.**

**Entrained bubbles are both relatively stable and useful for improving the properties of concrete. Stability is imparted to these individual bubbles by the formation of an insoluble layer derived from the reaction of lime and the air-entraining agent which envelops the air bubbles during mixing. They also stick to the particles of cement, preventing them from escaping to the surface.**

**Air can be entrained in concrete by two methods: air-entraining cements or air-entraining agents. Air-entraining materials include: salts of wood resins, synthetic detergents, salts and sulfonated lignin, salts of petroleum acids, salts of proteinaceous materials, fatty and resinous acids and their salts, and organic salts of sulfonated hydrocarbons. The material can be interground with the cement clinker or it may be introduced directly before or during mixing.**

The main advantage to using air-entraining cements rather than adding the air-entraining agent separately, is convenience. The addition of another component at the mixer and the problem of accurately measuring small amounts is eliminated. Air-entraining cements also have disadvantages. Most of them entrain less air than is needed for durability so an admixture frequently must be used anyway. When air entrainment is excessive, a non-air-entraining cement may be necessary in combination with the air-entraining cement to reduce the air content to the proper range.

The main advantage to the use of air-entraining agents as opposed to air-entraining cements, is the flexibility they allow. Alterations can easily be made to compensate for the various conditions that influence the air content or for operations where a variety of concrete mixtures is produced. The engineer or inspector can usually maintain better control of the concrete mixture. Air-entraining admixtures must be dispensed accurately using devices that allow the fluid to flow at a given rate for a set time, that allow a previously measured quantity or weight to flow into the mixer, or that use a flow-meter to measure a given amount of admixture.

## EFFECTS

The effects of air entrainment on concrete in the plastic state are improved workability, placeability, reduced bleeding, and, in some instances, lower cost. The billions of minute air bubbles provide a lubricating effect and have an effect on workability similar to adding additional water. In structural work the mix easily assumes intricate shapes. It also flows easily around closely spaced reinforcing bars. Since the volume of the paste is increased, lean mixes and mixes with angular or poorly graded aggregates are more workable. Better finishing usually results because greater plasticity allows a smoother, faster finish. Also, finishers can usually start sooner due to reduced surface water. Occasionally trowelled finishes may blister or surfaces may crust while drying conditions prevail.

In a sense, the bubbles can be considered a third aggregate. Because of their small size, the bubbles act as fines, thereby cutting down the amount of sand needed. Because air entrainment produces increased slump, it is possible to decrease the amount of water to get higher strengths without affecting workability. Thus, air-entrained concretes will have lower water-cement ratios than non-air-entrained concretes and reductions of strength that generally accompany entrainment of air are minimized. However, some reductions in strength may be tolerable in view of other benefits. These reductions become significant only in mixes containing more than about 565 lb. of cement per cu. yd. In leaner or harsher mixes, strengths are generally increased by entrainment of air in proper amounts.

Attainment of high strength with air-entrained concretes may be difficult at times. Both air-entrained and non-air-entrained concretes have increased water demands when slumps are maintained constant as concrete temperatures rise. Even though a reduction in mixing water is associated with air entrainment, mixtures with high cement contents require more mixing water; hence, the increase in strength expected from the additional cement is offset somewhat by the additional water added. Also, with some aggregates it is not possible to secure extremely high strengths with air-entrained concrete. In all such cases, however, other benefits, such as improved durability and workability, are not impaired.

Bleeding in concrete is cut approximately in half by entrained air because many capillaries terminate in "dead-end" bubbles. This reduces the adverse effects of a higher water-cement ratio at the surface of slabs and of laitance forming on concrete surfaces. It permits earlier finishing.

The air-void system in the mortar imparts a buoyant action to the cement and aggregate particles which prevents settlement. Less segregation is experienced and more attractive surfaces are achieved. Reduced segregation is critical when concrete is being pumped with air equipment. The lubricating effect of air entrainment also demands less work on the part of the pumping mechanisms.

In hardened concrete the outstanding attributes of air entrainment are resistance to weathering and scaling. A properly designed mix with lowest possible water content will improve the durability of the concrete.

Concrete exposed to repeated cycles of freezing and thawing is sometimes damaged or destroyed. The principal forces inducing such damage are internal hydraulic pressure created by the expanding ice-water system and the growth of ice crystals in capillary cavities. When water in a saturated capillary cavity or pore freezes, the expansion produced in the ice-water system requires a dilation of the cavity of about 9 percent of the volume of the water which freezes. This forces that volume of water out of the cavity into the surrounding paste producing hydraulic pressure.

The magnitude of the hydraulic pressure depends upon:

1. Distance from the cavity to a point of pressure relief
2. Degree of saturation
3. Rate of ice formation
4. Permeability of the intervening material
5. Degree of elastic accommodation of the material around the cavity.

If the pressure developed is too high, the paste will be damaged. Of the four items determining the amount of pressure, only the first--the distance from the cavity to a point of pressure relief--can be modified to the extent necessary to prevent damage under severe freezing and thawing conditions. The controlled entrainment of air in concrete serves this purpose.

In any system of voids, moisture tends to move from larger voids to smaller ones because of surface tension. The entrained air voids, while very small, are far larger than the capillary voids and normally remain essentially free of moisture. They serve as points of pressure relief when moisture is forced out of the capillary voids during freezing. Upon thawing, this moisture is drawn back into the capillary voids by capillary force. Thus, a neat and automatic pressure relief system is built into the concrete.

If enough entrained air voids are present so that no capillary void is more than about 0.008 in. from an entrained air void, experience has shown that destructive damage due to freezing and thawing will not occur in the paste fraction of normal concrete under normal conditions of exposure.

Scaling is also caused by severe freezing and thawing conditions and by the wide use of salts as de-icing chemicals. Salt scaling can be caused by either the direct application of the salts to the concrete or by indirect application of salt drippings from undersides of automobiles. Such damage can almost entirely be prevented if the concrete is air entrained, properly cured, and is made with an adequate cement content, a low water-cement ratio, and sound aggregates.

These conclusions about the durability of air-entrained concrete have only been made after thorough, long-term studies by several different sources.

The Portland Cement Association initiated a long-time study of cement performance in concrete in 1941 in which construction variables and exposure conditions were controlled to an extent that permitted direct comparisons between cements. Twenty-seven cements with wide differences in chemical composition and fineness were used in full-size construction, nearly job-size structures, and laboratory-size specimens for exposure in projects widely scattered throughout the country, representing the full range of exposures likely to be encountered. All five ASTM C150 types of cement and ASTM C175 air-entraining types IA, IIA, and IIIA were used.

The conclusion reached is that air entrainment is an important requirement of frost-resistant concrete and that adjustments in either the chemical composition of cement or fineness of grinding, or methods of manufacture have relatively little effect on increasing frost resistance of concrete when compared to air entrainment.

The Bureau of Public Roads has made several extensive studies of the durability of concrete with air entrained by different air-entraining agents. In these studies, slabs 16 x 24 x 4 in. with a raised edge or dam around the perimeter of the top surface have been used as test specimens. These slabs were stored out of doors. During cold weather when freezing was expected, the top surface of each slab was covered with 1/4 to 1/2 in. of water. The next morning after the water had frozen, commercial calcium chloride flakes were applied uniformly at the rate of 2.4 lb. per sq. yd. of surface.

The slabs were examined at intervals and rated for surface scaling. Ratings were based on observations of extent and depth of scaling. All of the air-entraining agents used were effective in varying degrees in delaying the start of significant scaling.

Air contents for both air-entrained and non-air-entrained concretes are plotted against the number of cycles required to reduce the modulus of elasticity by 50 percent. (see Fig. 1) All the non-air-entrained concretes had low resistance to freezing and thawing regardless of composition of fineness of the cements, cement content, or water-cement ratio of the concretes. As the air content of the concrete was increased by the use of an air-entraining agent, resistance to freezing and thawing also increased. Concretes with air contents increasing from 3- to 6-percent show resistance even after 1250 or more cycles of freezing and thawing. These results demonstrate that the air content of the concrete is far more significant with regard to freeze-thaw resistance than the fineness or composition of the cement.

Box-type specimens, 30 in. sq., cast in place, and filled with sand and water were built in 1942 as part of another long-time study. The sand was kept moist continuously to simulate concrete retaining walls and similar structures constantly exposed to moist soil. The test plot was located at Naperville, Illinois,

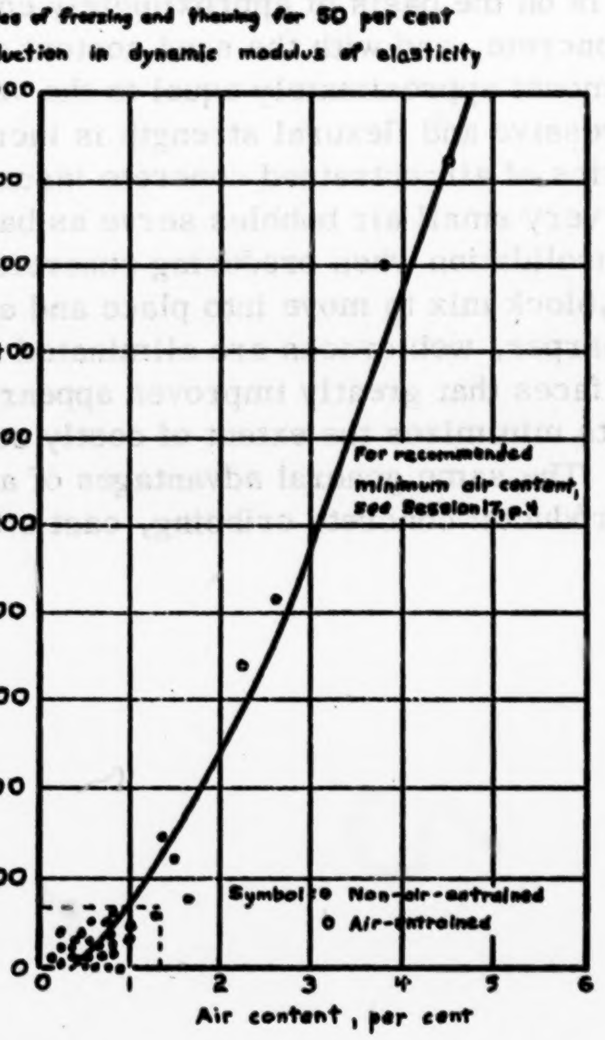


Fig. 1. Effect of entrained air on the resistance of concrete to freezing and thawing. Concretes were made with cements of different fineness and composition, various cement contents, and water-cement ratios.

**where conditions of freezing and thawing are severe. After years of severe exposure air-entrained concrete proved far more durable.**

**Sulphate resistance is heightened by use of air entrainment. Although low water-cement ratios and the use of Type II, Type V, or other cements low in tricalcium aluminate, are of primary importance in lessening the effects of sulphate attack on concrete, air entrainment is extremely helpful.**

**Watertightness of air-entrained concrete is superior to that of non-air-entrained concrete. The air-void system interrupts an otherwise continuous capillary system, thus decreasing permeability.**

**Compressive strength is the most important factor controlling the resistance of concrete to abrasion. The resistance increases as the compressive strength increases. The air content of the concrete influences its resistance to abrasion only insofar as it affects the compressive strength. Air-entrained concretes are as resistant to abrasion as plain concretes provided they are designed for equal strength.**

**For usual class A structural concrete (560 lb. per cu. yd. and 3-in. slump) air entrainment causes a reduction in compressive and flexural strength of approxi-**

mately 10 percent. This is on the basis of approximately equal cement content and slump for both types of concrete, and with the sand content of the air-entrained concrete reduced by an amount approximately equal to the volume of entrained air. For leaner mixes, compressive and flexural strength is increased.

The characteristics of air-entrained concrete insure improved surface texture. The myriads of very small air bubbles serve as ball bearings to give better compaction and better consolidation when producing concrete masonry, for instance. They enable a harsh, dry, block mix to move into place and against form faces. Corners and edges are sharper, web cracks are eliminated and stripping operations produce a sheen on block faces that greatly improves appearance. Reduced bleeding at horizontal surface joints minimizes the extent of costly surface preparation to remove surface laitance. The same general advantages of air entrainment can be obtained in all concrete products: concrete cribbing, cast stone, precast concrete piles, etc.

## DISCUSSION QUESTIONS

1. List four effects on fresh concrete due to the use of entrained air. Explain each effect.
2. List the four effects air entrainment has on hardened concrete and explain each.
3. What are the two methods used to obtain air entrainment in concrete?
4. What is the principal reason for using air-entrained cement?

PRINCIPLES OF CONCRETE Unit 2, Session 17
Air-Entrained Concrete

## GENERAL OBJECTIVE

To develop an understanding of the proper level of air content in concrete.

## PERFORMANCE OBJECTIVES

The student should be able to list the factors that affect air content.

The student should be able to describe the difference in air content used for structural concrete and insulating concrete.

## INTRODUCTION

The amount of air to be entrained depends upon the intended use and maximum aggregate size of the concrete. It is not feasible to hold the air content percentage completely constant because air content is affected by many factors.

## OVERVIEW OF SESSION

In this session the main discussion will be about the optimum air content of concrete and what factors affect this level of air content.

## SESSION OUTLINE

I. Recommended Air Content
  A. Aggregate size
  B. Workability

II. Factors Affecting Air Content
  A. Aggregate gradation
  B. Mix proportions
  C. Fine aggregate content
  D. Slump and vibration
  E. Concrete temperature
  F. Mixing action
  G. Coloring agent

## RELATED ACTIVITIES

1. **Secure different sizes of aggregate and explain the use of each size and its effect on the air content.**

## TOOLS AND MATERIALS

LITERATURE

**Air-Entrained Concrete, (IS 045.02T), from PCA**

<table>
<tr><th>Presentation Outline</th><th>Teaching Techniques, Aids & Devices</th></tr>
<tr><td>I. Recommended Air Content<br>A. Aggregate size. Air content varies with aggregate size. The following table shows the recommended air content and aggregate size.</td><td>Make demonstration using different size aggregates.</td></tr>
<tr><td><table>
<tr><th>Max. Size Aggregate</th><th>Percent Air</th></tr>
<tr><td>1-1/2 to 2-1/2 in.</td><td>5 ± 1</td></tr>
<tr><td>3/4 to 1 in.</td><td>6 ± 1</td></tr>
<tr><td>3/8 to 1/2 in.</td><td>7-1/2 ± 1</td></tr>
</table></td><td>Use IS 045.02T as a hand-out.</td></tr>
<tr><td>II. Factors Affecting Air Content<br>A. Aggregate gradation. Gradation of aggregates will partially determine the air content of the concrete mix.<br>B. Cement content<br>C. Fine aggregate content. The amount of entrained air increases as the amount of fine aggregate increases for a given amount of admixture or air-entraining cement.<br>D. Slump and vibration. Both affect the amount of air retained in finished concrete.<br>E. Concrete temperature. As temperature of concrete increases, less air will be entrained.<br>F. Mixing action. Affects entrained air depending on type and condition of mixer, amount being mixed and rate of mixing.</td><td>Use IS 045.02T (Fig. 6). Explain in detail.</td></tr>
<tr><td>G. Coloring agent. Certain coloring agents contain a high percentage of fines that render air-entraining agents less effective.</td><td>Review ways of adding air to concrete.</td></tr>
</table>

## RELATED INFORMATION

## RECOMMENDED AIR CONTENT

**The optimum air content of a concrete is considered to be the minimum air content beyond which further increases in air result in only marginal improvement in resistance to freezing and thawing. This air content is optimum in the sense that it is a balance point between increase in durability and reduction in strength.**

**The amount of air to be entrained also depends upon the intended use and desired weight of the concrete. Structural concretes should have less air than insulating types.**

**The desired air content varies with the maximum aggregate size. The nature of the coarse aggregate determines amount of mortar needed for workability. The larger the aggregate, the less mortar needed. Since entrained air exists in the paste, the less mortar needed, the less air entrained. The mortar component of air-entrained concrete should be adjusted so it contains about nine percent air.**

| If maximum coarse aggregate is | Specify |
|---|---|
| 1-1/2 to 2-1/2 in. | 5 percent air ± 1 |
| 3/4 to 1 in. | 6 percent air ± 1 |
| 3/8 to 1/2 in. | 7-1/2 percent air ± 1 |

**It is not feasible to hold the percentage absolutely constant because air content is affected by many factors including: maximum size of coarse aggregate, type and gradation of aggregate, hardness of water, length and means of mixing, brand of cement, concrete temperature, etc. A common specification allows for variation of plus or minus 1 percent.**

## FACTORS AFFECTING PERCENT OF AIR ENTRAINED IN CONCRETE

**Several factors affect air content. Mix proportions, aggregate size and gradation, mixing operations, concrete temperature, the use of other admixtures, and vibrating and finishing procedures all have their unique effects.**

**Mixing action is the most important factor in the production of entrained air in concrete. Uniform distribution of entrained air voids is essential to scale-resistant concrete. Non-uniformity may result from inadequate dispersion of the entrained air during mixing. The amount of entrained air varies with the type and condition of the mixer, the amount of concrete being mixed and the rate of mixing. A stationary mixer and a transit mixer may develop a significant difference in the amount of entrained air due to differences in mixing action and time. An increase in air content may occur if the mixer is loaded to less than rated capacity and a decrease may result from overloading the mixer. More air is entrained as the speed of mixing is increased.**

The changes in air content with prolonged agitation is explained by the relationship between slump and air content. When initial slump is greater than 7 in., the air content increases with continued agitation while the slump increases to about 6 to 7 in. Continuing agitation will further decrease slumps and air contents as well. For initial slumps lower than about 6 to 7 in., the air content decreases as slump decreases with continued agitation.

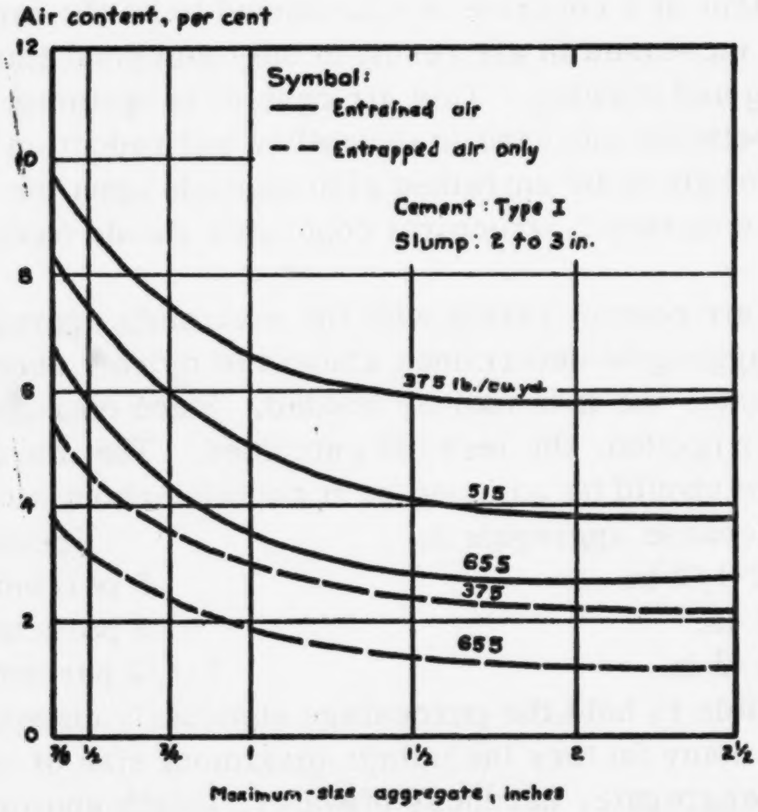


Fig. 2. Typical relationship between aggregate size, cement content, and air content of concrete.

Aggregate gradation and mix proportions affect both air-entrained and non-air-entrained concrete (Fig. 2). Tests illustrated in this graph were made with concretes having slump of 2-3 in. and cement contents of 4, 5-1/2, and 7 bags per cu. yd. There is little change in air content when the maximum size of aggregate is increased above 1-1/2 in. For aggregate sizes smaller than 1-1/2 in., the air content increases sharply as the aggregate size decreases.

This graph also illustrates the effect of cement content on the amount of entrained air. Richer mixes entrain less air while leaner mixes entrain more air. This relation applies whether the air is entrapped or intentionally entrained.

Fine aggregate content of a mix also affects the percentage of entrained air. Increasing the amount of fine aggregate causes more air to be entrained for a given amount of air-entraining cement or agent. Fine aggregate particles in the middle sizes result in more air than the very fine or coarse sizes. Fines passing No. 100 and especially No. 200 sieves decrease air entrainment.

Concrete temperature must be considered. Less air is entrained as the temperature of the concrete increases. Also, the effect of temperature becomes more pronounced as the slump is increased. The effect of temperature is especially important during hot-weather concreting when concrete might be quite warm. Increasing the mixing temperature from 70 to 100° F. may reduce the air content 25 percent while reducing the temperature to 40° F. may increase the air as much as 40 percent. In cold weather admixture dosages should be reduced to prevent loss of strength.

Vibration time with air-entrained mixes should be shortened and kept reasonably constant since it tends to dispel the air. A normal amount of vibration (about 1/2 minute) reduces the initial air content about 10 percent. When vibrated one minute, the air content is lowered 15 to 20 percent. In addition, internal vibration reduces air more than external vibration.

Certain coloring agents (especially carbon black and black iron oxide) and other admixtures add a large percentage of fines to the concrete, rendering the air-entraining agent less effective. Generally, air-entraining agents should be added to the mixer separately from other admixtures being used unless tests have shown this to be unnecessary.

## DISCUSSION QUESTIONS

1. What is the optimum air content for concrete?
2. Explain the difference in air content used for structural concrete and insulating concrete.
3. List the seven factors that affect air content in concrete and explain each briefly.

PRINCIPLES OF CONCRETE Unit 2, Session 18
Air-Entrained Concrete

## GENERAL OBJECTIVE

To develop a complete understanding of the standard tests used to determine the air content of concrete.

## PERFORMANCE OBJECTIVES

The student must be able to list and explain the three standardized methods of testing concrete.

## INTRODUCTION

It should be emphasized that specifying air entrainment is not enough in itself. Widespread use of air-entrained concrete in the United States and Canada has led to the development of a number of methods of determining air content in plastic and hardened concrete.

With plastic concrete, air determinations should be made by competent inspectors at such intervals as may be necessary to insure compliance with the specifications.

## OVERVIEW OF SESSION

**In this session the instructor will be discussing and demonstrating the various methods of testing for air content. Each student should have an opportunity to perform the various tests for air content.**

## SESSION OUTLINE

**I. Testing for Air Content in Fresh Concrete**
  - **A. Standard tests**
    - **1. Gravimetric method**
      - **a. High silhouette meters**
      - **b. Low silhouette meters**
    - **2. Volumetric method**
      - **a. Roll-a-meter**
      - **b. Chase air indicator**

**II. Testing for Air in Hardened Concrete**
  - **A. Optical methods**
    - **1. Linear traverse method**
    - **2. Modified point count method**

## RELATED ACTIVITIES

1. **Make air content tests using the various methods that have been discussed.**
2. **Plan a field trip where they are testing concrete for air content.**

## TOOLS AND MATERIALS

SLIDES

From PCA:
- Nos. 2512, 2514, 2515, 2517, 2518, 2519, 2520, 2521, 2522, 2567, 2628 -- Chase Air Indicator and how to use it.
- No. 6157 -- Roll-A-Meter
- No. 5746 -- High silhouette pressure air meter
- No. VII-B-2 -- "Making unit-weight test of plastic concrete with 1/4-cu. ft. bucket and beam scale."

Note to Instructor: See Index to Quality Concrete Slide Reference File for complete listing of slides on this subject.

| Presentation Outline | Teaching Techniques, Aids & Devices |
|---|---|
| I. Testing for Air Content in Plastic Concrete | |
| A. Standard tests. Three basic methods commonly used | |
| 1. Gravimetric method - absolute volume used as basis for test<br>a. High silhouette meters<br>b. Low silhouette meters | Show slides of Chase Air Indicator, High Silhouette Pressure Air Meter, and Roll-A-Meter--or actual meters if available. |
| 2. Volumetric method - air content measured directly<br>a. Roll-a-meter<br>b. Chase air indicator | |
| II. Testing Air Content in Hardened Concrete | |
| A. Optical methods best means | |
| 1. Linear traverse method measures chord lengths of air voids . | |
| 2. Modified point count method is similar but varies by substituting a series of closely spaced points on a line. | |

## RELATED INFORMATION

### TESTS FOR AIR CONTENT

**It should be emphasized that specifying air entrainment is not enough in itself. Widespread use of air-entrained concrete in the United States and Canada has led to the development of a number of methods of determing air contents in plastic and hardened concrete.**

**With plastic concrete air determinations should be made by competent inspectors at such intervals as may be necessary to insure compliance with the specifications. If two consecutive determinations of separate batches at the beginning of a day's run show adequate amounts of air, an occasional check, such as one per five loads, should be sufficient evidence of continuing compliance. Samples for air tests should be taken from the ready mix truck.**

**When air-entraining agents are used, it is necessary to control the air content of the concrete within about ± one percent limits to maintain uniform workability, strength and durability. The quantity of air-entraining agent to be used should be adjusted up or down, as indicated by the results of the test.**

**The air content of concrete is the relationship between the volume of air in the paste and the total volume of the concrete. It is normally expressed by the equation:**

$$\text{Percent Air} = \frac{\text{Volume of Air in Paste} \times 100}{\text{Total Concrete Vol.}}$$

**Test methods to be described here can only measure the total percentage of entrapped air (large bubbles) and entrained air (small bubbles); one kind of "air" cannot be distinguished from the other.**

**There are three distinct methods of test used to determine the air content of plastic concrete. These are the gravimetric, pressure and volumetric methods of air content determination.**

### Gravimetric Method of Air Content Determination

**A little later you will be introduced to the absolute volume method of concrete mix design. One factor in this design procedure is the determination for a concrete batch of the absolute volumes of the solid materials which are the water, cement, sand, and coarse aggregate. The absolute volume of one of these solid materials is the volume that the material occupies in the concrete. For example, if you could mix a batch of mortar and determine its volume, then mix coarse aggregate in the mortar and determine the volume of the resulting concrete, the difference between the volumes of mortar and concrete is the absolute volume of the coarse aggregate added to the mix.**

Normally, absolute volumes of materials are not found by the direct method just mentioned. Instead, they are determined from calculations involving the weight of the material and its specific gravity. In later sessions, you will learn how to determine and use specific gravity values. Specific gravity being a function of the weight of a material in relation to an equal volume of water. Here, only the use of absolute volumes in determining the gravimetric air contents of concrete will be considered.

Example of gravimetric air content determination:

Assume that a small concrete operation has a 1-cu. yd. mixer and consistently mixes concrete with the batch weights given in TABLE 1. Knowing the specific gravity of each material, it is possible to calculate the absolute volume of each concrete component. These values are also given in TABLE 1.

TABLE 1

CONCRETE BATCH QUANTITIES

| | Batch Weight lb. | Absolute Vol. cu. ft. |
|---|---|---|
| Cement | 564 | 2.82 |
| Water | 275 | 4.41 |
| Sand | 1055 | 6.33 |
| Gravel | 2050 | 12.30 |
| | 3944 Total | 25.86 Total |

With the information in TABLE 1, it is simple to determine the hypothetical unit weight of the concrete (UWN is a convenient abbreviation) if the concrete contained absolutely no air. This value would be the calculated total absolute volume of all the solid concrete components divided by the sum of their weights or:

hypothetical airless absolute volume (UWN) - $\frac{3944 \text{ lb.}}{25.86 \text{ cu.ft.}}$ = 152.5 lb./cu.ft.

Naturally, the actual unit weight of the mixed concrete will be less than this hypothetical value because all concrete contains at least some air, which is a material that occupies volume in the concrete but has no significant weight. The actual unit weight of the concrete (UW) is needed to calculate the concrete air content by gravimetric means. It may be determined by compacting concrete into a container of known volume, weighing the concrete filling the container, and determining the actual unit weight of the concrete by dividing the concrete weight (in lb.) by the volume of the container (in cu.ft.).

Assume that the actual unit weight of the concrete in the preceding example was measured and the unit weight found to be 143.0 lb. per cu.ft.

The gravimetric air content of the concrete may then be determined using the hypothetical solid unit weight of the concrete (UWN) and the actual concrete unit weight (UW) using the formula:

$$\% \text{ Air} = \frac{UWN - UW}{UWN} \times 100$$

In our example, with UWN - 152.5 lb./cu.ft. and UW - 143 lb./cu.ft., the calculated gravimetric air content is:

$$\% \text{ Air} = \frac{152.5 - 143.0}{152.5} \times 100 = \frac{9.5}{152.5} \times 100 = 6.2\%$$

The gravimetric air content depends upon a number of factors which must be measured quite accurately. For that reason, air contents determined gravimetrically will only be approximate and not as accurate as those found by other methods in which air contents are measured by direct test.

## Air Content Determination by Pressure Tests (ASTM C231)

Air, whether we breathe it or whether it is small bubbles in concrete, is a gas and obeys certain physical principles, the "gas laws", that relate volume changes in an entrapped gas to pressure changes in the gas. Concrete technicians use various kinds of "pressure meters" to determine directly the air content of a concrete charge. These air meters subject the concrete to external pressures and then measure induced volume of pressure changes in the concrete. Through suitable calibration and design based on the gas laws, these pressure meters are manufactured so that they give direct readouts of concrete air content. Two different kinds of pressure meters will be considered here. They are the "high silhouette" and the "low silhouette."

## "HIGH SILHOUETTE" AIR METERS

Among several good air meters of this type the Acme meter is one of the most popular. Fig. 3 is a schematic drawing of this type air meter, showing the meter bottom or concrete pot, in which concrete to be tested is compacted and struck off, the air meter top which resembles an inverted funnel, and accessories such as the pressure gage, clamps, air pump, and the top cap. As shown in the figure, the top portion of the air meter above the concrete charge is filled with water. The upper top necks down into a small diameter transparent tube so that small changes in the combined air meter charge of concrete and water result in a significant change of water level in the stack. When the concrete pot is filled, the air meter assembled, and the device filled with water, one substance in the meter is very compressible--that is, the air that is either entrapped or entrained in the concrete. The water and cement are incompressible and the fine and coarse aggregate have little compressibility. The quantity of air entrained in the concrete is determined through the simple process of pumping air into the meter until the pressure gage at the very top of the meter reads a fixed predetermined "Operating air pressure," then reading percent air as

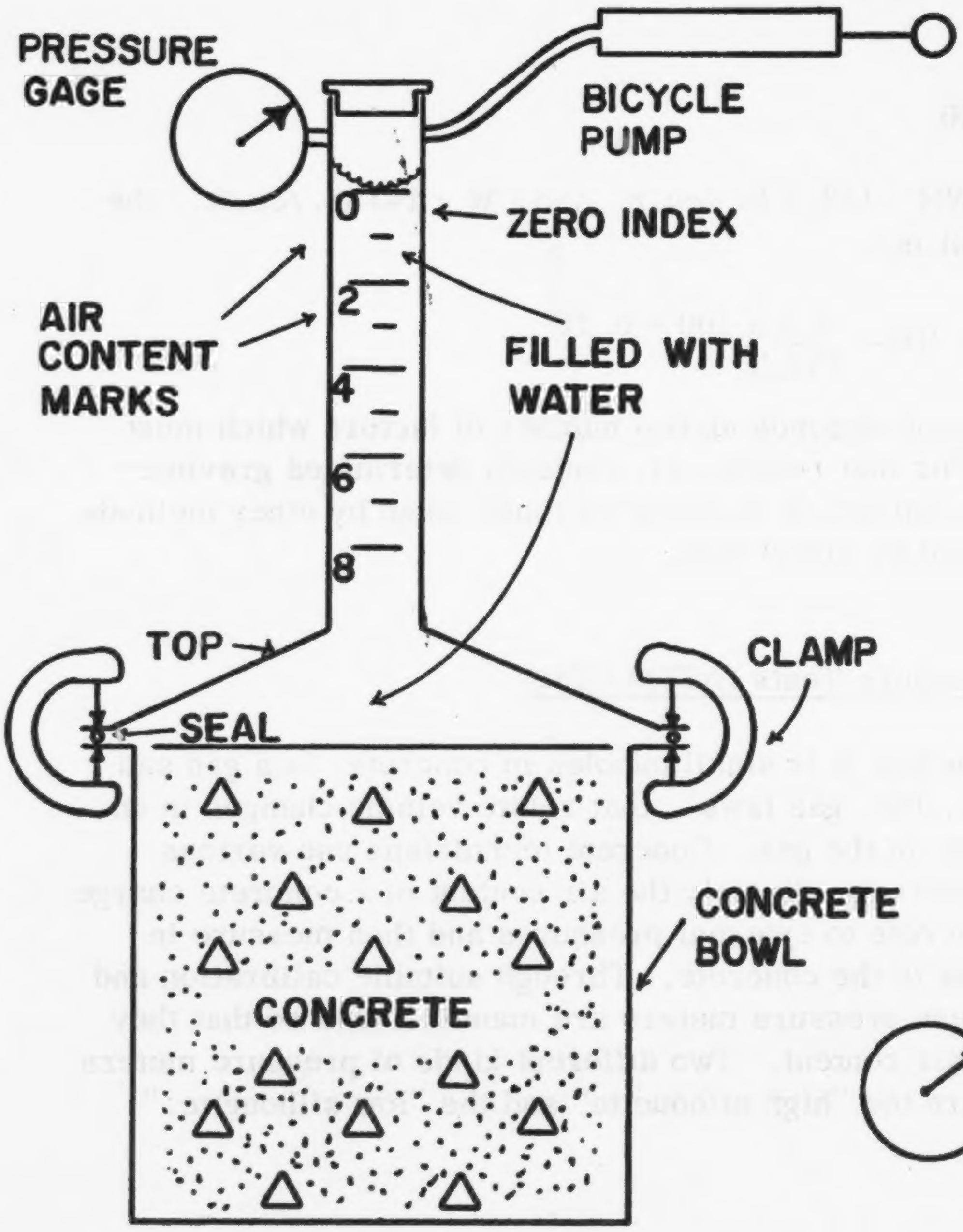

PRESSURE GAGE
BICYCLE PUMP
0
ZERO INDEX
AIR CONTENT MARKS
2
4
6
8
FILLED WITH WATER
TOP
CLAMP
SEAL
CONCRETE BOWL
CONCRETE

Fig. 3
"HIGH SILHOUETTE" TYPE
AIR METER
CONCRETE AIR TEST SETUP

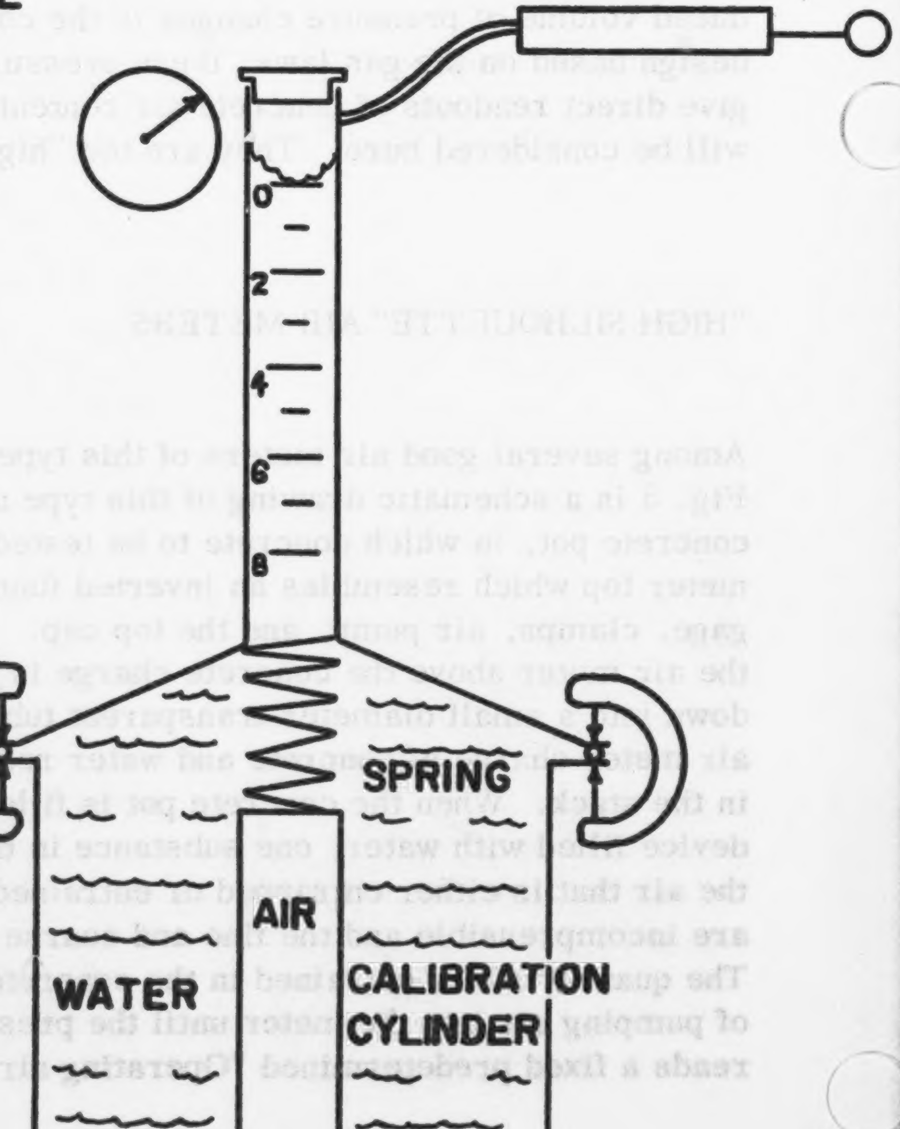

0
2
4
6
8
SPRING
AIR
WATER
CALIBRATION CYLINDER

Fig. 4
"HIGH SILHOUETTE" TYPE
AIR METER
CALIBRATION SETUP

indicated by the stack water level. If the concrete in the meter contains a great deal of air, the air meter charge will be compressed considerably and the surface of water in the top stack will drop a long way. If the concrete contains no air, the air meter charge will be incompressible and the surface of water in the top stack will hardly fall. All this is in accord with the principle of physics known as Boyle's Law ($P_1V_1 = P_2V_2$) which governs the relationship between the pressure and volume of a gas.

A ruler-like scale is set close to the surface of the transparent stack with the zero index at the top and numbered divisions increasing downward. The air meter is initially filled so that the water level in the stack is set at the zero index mark with the meter open and unpressurized. Increasing the pressure to the desired operating air pressure causes the water level in the stack to fall to an index mark equivalent to the percent air in the concrete. For example, if a concrete with 5% entrained air were compacted in a meter with an operating pressure of 8 psi, the height of the water column in the stack would be set at the zero index, the meter sealed, and the pressure on the meter raised to 8 psi gage. The water column would then fall from the zero index to the 5.0 index mark, indicating that the concrete charge had an air content of 5 percent. Refinements in measuring air contents, determining aggregate correction factors, calibrating the instrument, etc. are given in ASTM Method C231.

This type meter is commercially available in 1/2 and 1/4 cu. ft. sizes. They are not easily transported and take a lot of water to operate, making them less convenient for field tests than the other type of pressure meters. However, their simplicity, ruggedness, and accuracy make them extremely desirable for concrete work in laboratories in which they do not need to be moved.

The calibration of this type air meter involves the determination of the one operating pressure that will cause the water to lower from the zero index to a stack reading which absolutely matches the air content of the concrete compacted in the air meter bowl. Fig. 4 shows the setup normally used for the calibration of this air meter. A small cup is inverted in the empty air meter and held in that position by a spring action against the top of the meter. When the air meter is filled with water, a full cup of air is trapped inside the cup. The "percent air in the cup" may be determined as a percent of the volume of the bowl (which normally is filled with concrete during air tests) using the following relationship:

$$\%\text{ air in cup} = \frac{\text{Volume of Cup}}{\text{Volume of Bowl}} \times 100$$

To obtain a reasonably good air meter calibration and find the required operating pressure of the air meter, it is only necessary to determine by actual trial the gage pressure required to compress the air in the cup enough that the reading on the stack, in percent, matches the "percent air in the cup." For very critical test work, refinements in this calibration procedure are given in ASTM Method C231.

Because this meter is a pressure device, an aggregate correction factor must be made. This is necessary because the pores inside most aggregates are

**not completely saturated with water but filled with a mixture of water and air. Air in aggregate pores will be compressed during the operation of the air meter. Compression effects of aggregate pore air must be separated from that of intentionally entrained air in the concrete because entrained air, by definition, occurs as voids in the paste. Aggregate compressibility does not fall in that classification. The use of an aggregate correction factor permits calculation of the correct air content in concrete.**

**To determine the aggregate correction factor, fine and coarse concrete aggregate of the same kind, gradation, and moisture content as that to be used in the concrete is placed in the air meter, covered with water, and very thoroughly stirred to remove any air bubbles that may stick to the external surfaces of aggregate particles. An air test is then made of the aggregate in the same way as concrete is tested for air content. The "percent air" determined only on the aggregate is equivalent to the compression effects on pore air in concrete aggregate during air tests. The aggregate correction is made by deducting the "percent air" determined only on the aggregates. The difference is the "net air" content of the concrete and is the actual air content within the paste fraction of the concrete. More instructions for aggregate correction factor determination are given in ASTM Method C231.**

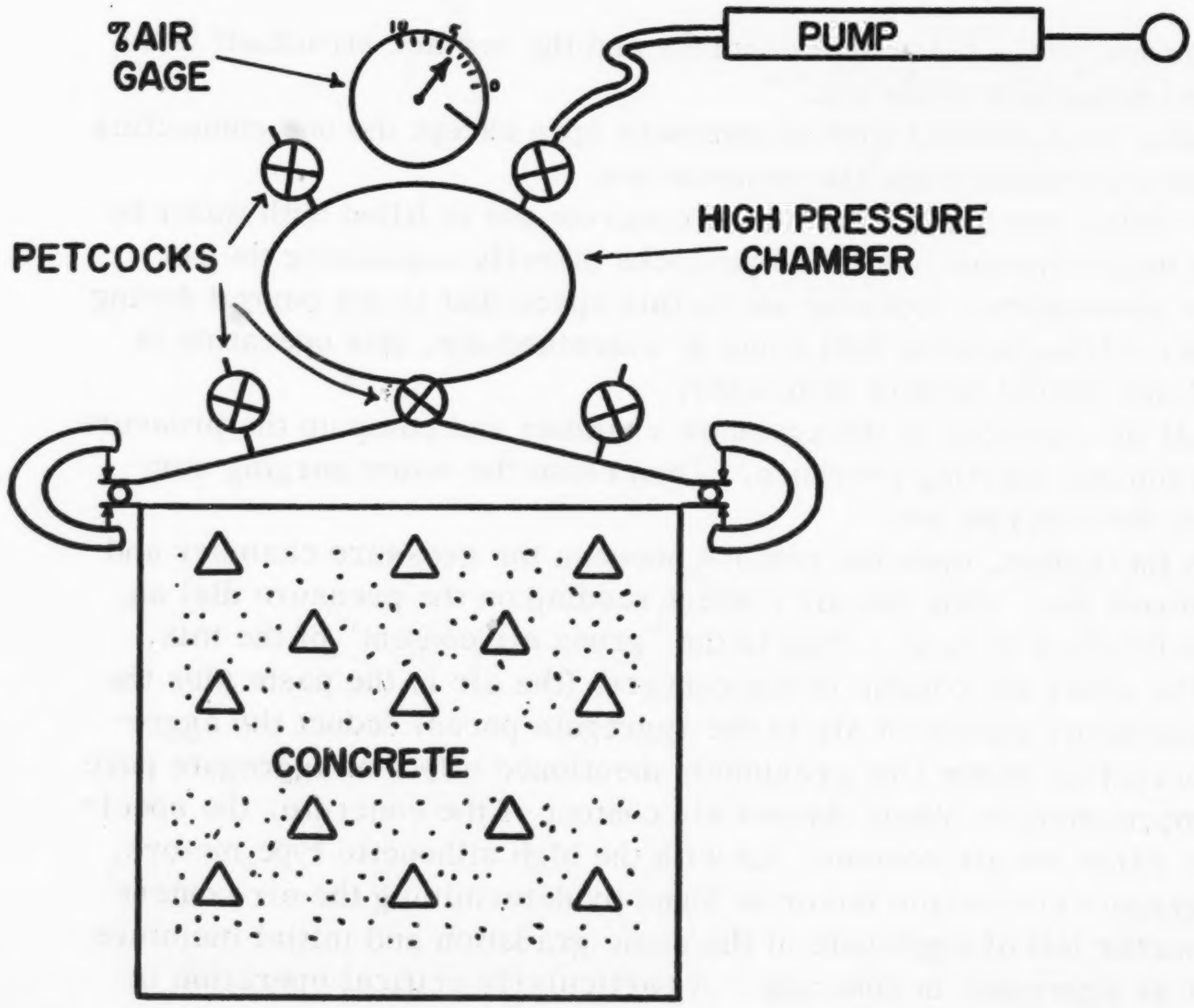
## "LOW SILHOUETTE" AIR METERS

**The "high silhouette" air meters are designed so that air contents are measured as a change in the volume of the air meter contents in response to a change in pressure inside the meter. Another kind of air meter, the "low silhouette" type, measures the air content of a concrete sample as a function of the change in pressure that occurs as a small volume of compressed air is jetted into the air meter. The first popular meter of this type was the "Washington Air Meter," which is no longer manufactured. Modernized versions such as the Press-ur-Meter, the Techkote meter and a number of other similar fine devices are used in the field and laboratory.**

**As indicated in Fig. 5, the main components of the low silhouette meter are a bottom container in which the concrete is compacted, and the top portion of the meter containing the air sensing devices. The air meter top consists of the meter closures (clamps and seals, a fixed volume pressure chamber, an air pump, a sophisticated air pressure gage with a special dial, and various valves to connect the top portion of the air meter to the concrete pot and to the outside).**

**The basic air sensing method used by these meters is to determine the pressure decay when air pumped to a high pressure in the top chamber is released into the bottom concrete-filled portion of the air meter. If the pressure loss is great, the air content of the concrete is relatively high. If the pressure loss is slight, the concrete contains little air. These reactions are dictated by the gas laws, which were used in designing the pressure gage so that it reads directly in percent air of the concrete compacted in the air meter pot. Air meters of this type are ideal for uses requiring a portable meter, and most air meters used in the field**

Fig. 5
"LOW SILHOUETTE" TYPE AIR METER


%AIR GAGE
PUMP
PETCOCKS
HIGH PRESSURE CHAMBER
CONCRETE

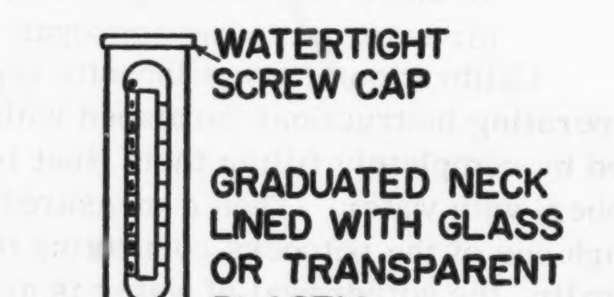

WATERTIGHT SCREW CAP
GRADUATED NECK LINED WITH GLASS OR TRANSPARENT PLASTIC
$V_1 = V_2$ (APPROX.)
TOP SECTION VOL = $V_2$
FLANGES WITH GASKET AND CLAMPS
MEASURING BOWL VOL = $V_1$
H
D=1 to $1\frac{1}{4}$ H

Fig. 6
ASTM C173
VOLUMETRIC AIR METER

appear to be of this kind. There are three main reasons for this portability: for a given concrete capacity, the low silhouette type meters have smaller bulk than the big silhouette type meters, require less water for testing, and finally they are more easily calibrated in the field than the other type.

In conducting an air meter test with these devices, the following procedure is used:

1. The concrete pot is filled with concrete and the surface struck off level with the top surface of the pot.
2. The meter is assembled with all petcocks open except the one connecting the pressure chamber and the concrete pot.
3. The air-filled space at the top of the concrete pot is filled with water by pouring water through one of the petcocks directly connecting the pot with the atmosphere. Because air in this space that is not purged during the water-filling process will count as entrained air, this operation is critical and should be done thoroughly.
4. Close all the petcocks to the pressure chamber and pump up the pressure to the required starting pressure. Then close the water purging stopcocks to the concrete pot.
5. Quickly thereafter, open the petcock between the pressure chamber and the concrete pot. Note the air content reading on the pressure dial as soon as it comes to rest. This is the "gross air content" of the mix.
6. From the gross air content of the concrete (the air in the paste plus the compressibility effects of air in the aggregate pores) deduct the aggregate correction factor (the previously mentioned effect of aggregate pore air compression) to obtain the net air content of the concrete, the specification value for air content. As with the high silhouette type meters, the aggregate correction factor is found by determining the air content of the meter full of aggregate of the same gradation and initial moisture content as aggregate in concrete. A particularly critical operation is an extremely thorough stirring and agitation of the aggregate so that no air external to the aggregate particles remains in the concrete pot.

Calibration of low silhouette type air meters should be done according to the operating instructions furnished with the meter. Most of the devices are calibrated by completely filling them (that is, all available space but the pressure chamber) with water. Then a measured amount of water is emptied from the meter through one of the petcocks connecting the concrete pot with the outside of the meter. Naturally, the withdrawal of water is accompanied by the introduction of an equal volume of air within the meter. This volume of withdrawn water and introduced air can be measured in the small volumetric container furnished with the meter, or might be calculated in milliliters or fluid ounces as about five percent of the concrete pot volume. Once the water is withdrawn and replaced with a known percentage of air, an air test can be run on the water-air charge of the meter, and the percent air read with the meter determined. If the tested air content value is above or below the actual percentage of air in the meter, the meter can be recalibrated by changing the zero index point of the meter.

## VOLUMETRIC AIR METERS

**One of the old-style procedures for determining concrete air content was a direct determination of air content through the use of a yield bucket, a hook gage, the rod normally used for concrete test compaction, and a milliliter graduate. The half cu. ft. yield bucket is filled with compacted concrete up to an index mark 3/8ths of the way up the inside wall of the bucket. Then water is poured atop the concrete until the bucket is filled to a 3/4 height. This water level is critical and controlled by the use of a hook gage. The hook gage is removed, and the water and concrete stirred into a slurry of such fluidity that the entrained and entrapped air bubbles rise to the top of the slurry. Loss of the air bubbles causes the water level to lower in the bucket. The exact volumetric loss of air may be determined by replacing the hook gage and pouring in water from a graduate until the precise initial height of fluid in the unit weight container is restored. Air content in percent is measured as the volume of concrete (in ml.) divided by water added from the graduate (in ml.) times 100. This old style procedure illustrates the "volumetric" air determination technique, in which concrete is reduced to a slurry, the air is removed, and the loss of air determined volumetrically and then converted to a percent of the total concrete volume.**

**One more modern volumetric procedure is still widely used. This test method is outlined in ASTM Method C173. One commercially produced meter meeting this specification is the "Roll-a-meter." A concrete sample tested with such a meter is quite small (less than 1/10 cu. ft.) and the test procedure takes longer and is somewhat more work than testing with a pressure meter. However, one facet of testing that makes the volumetric method superior to the pressure procedure is in the testing of lightweight aggregate concrete. Large aggregate correction factors and the complex, time-consuming pressurization of air voids in lightweight aggregate makes testing lightweight aggregate concrete with a pressure meter quite difficult and somewhat inaccurate, even when done by experts. Because volumetric test procedures give the true air content of only the paste, no aggregate correction factor is needed with this technique. As a result, the Roll-a-meter is an extremely popular and effective device for the testing of lightweight aggregate concrete.**

**The Roll-a-meter, a schematic diagram of which is given in Fig. 6, consists of the concrete pot at the bottom, a top equipped with permanently mounted clamps, a screw cap, and a little alcohol measuring jigger with a volume equal to one percent of the concrete pot. To run an air test with the Roll-a-meter the following test sequence is used:**

1. **Concrete is compacted in the pot and struck off flush with the top.**
2. **The top is attached to the pot, filled with water to the index mark at the very top of the narrow tube extending from the top. Then the cap is screwed on.**
3. **The concrete-water meter charge is reduced to a slurry and the air bubbles washed to the top of the slurry. This is done by inverting and re-inverting the meter several times, then grasping the top tube and rolling the whole meter back-and-forth on a flat surface for at least 2**

or 3 min., then bringing the meter upright gradually so that all the air meter foam rises into the stack, which has a transparent sidewall calibrated in percent of the volume of the concrete pot.

4. Break the foam. A good reading is impossible so long as 2 or 3 in. of foam, which contains an appreciable volume of water and cement, sits atop the slurry in the air meter. The foam is broken with alcohol so that the bubbles disappear and the solids sink to the bottom of the meter and a good reading can be taken. Two or three jiggers of alcohol (rubbing isopropyl is best, wood alcohol will do) in the screw cap may have to be added to break the foam. Each jigger of alcohol raises the liquid level in the stack exactly 1%, so be certain to count the number of jiggers added to break the foam and add this number to the reading on the air meter to determine the percent air in the concrete.

One advantage of the Roll-a-meter is that it needn't be calibrated if it is in usable condition. There are no moving parts used in determining the air content of the concrete.

Another volumetric device deserving mention is the small glass air indicator distributed by various scientific and engineering supply houses. It has been called the Chace air indicator, and is sometimes called the AE-55 air indicator. The device is much like a miniature Roll-a-meter, and is used to check the volumetric air content of about a thimble-full of mortar taken from a concrete mix. Since it is used to test mortar from concrete, and concretes have variable mortar contents, a mortar content correction is appropriate to convert AE-55 readings to air content percentages for concrete.

Capable operators can sometimes do surprising things with this little device, and may hit the actual air content within 1% or even .5%. Inexperienced or incapable operators often do a very bad job with this instrument, and their results are only of value in indicating whether or not the concrete was intentionally air entrained.

The value of this instrument, and the uses to which it might best be put, are still a matter of considerable discussion. Some give it unqualified praise, others equivalent condemnation. Some suggest a middle course, in which the strengths of the instrument (its portability, small size, and short test time) may be utilized by using it to test many more concrete batches than might be tested with a full-sized air meter and in this way to determine those concrete batches that might deserve closer inspection with a full-size air meter.

Fig. 8 shows the separated glass body and the combination sample thimble and rubber stopper body closure. Fig. 9 shows the difficult method for filling the sample thimble with mortar: separating the mortar from large particles using a jacknife or some sort of spatula. The sample-splitting spoon shown in Fig. 10 is a better, faster method. The slot in the spoon acts as a screen for coarse particles as the bowl of the spoon is slid across the finished concrete in a direction vertical to the slot. Fines work through the slot and accumulate rapidly in the bowl of the spoon, from which the material can easily be deposited in the sample thimble by jarring it on a table and rodding with a small paperclip (Fig. 11). When the sample thimble is full, the mortar is struck off (Fig. 12), the inverted indicator body partially filled with alcohol (Fig. 13), and the stopper and thimble inserted into the

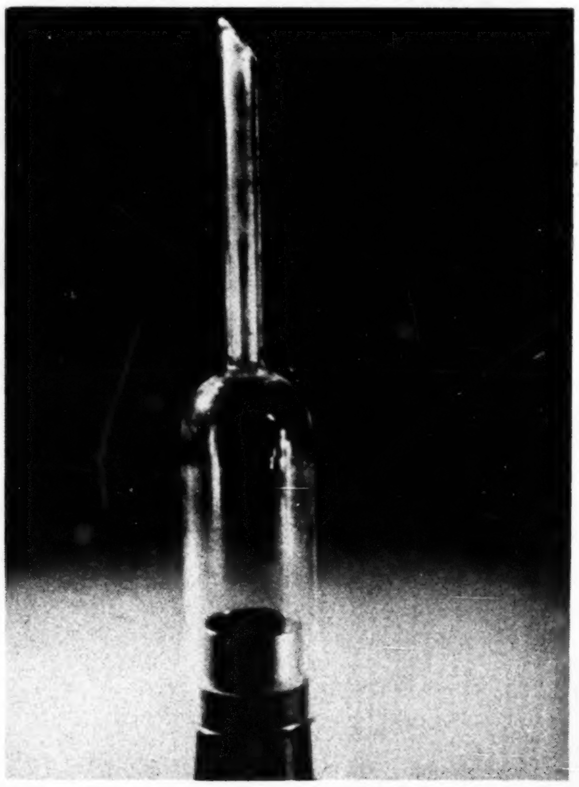


Fig. 7

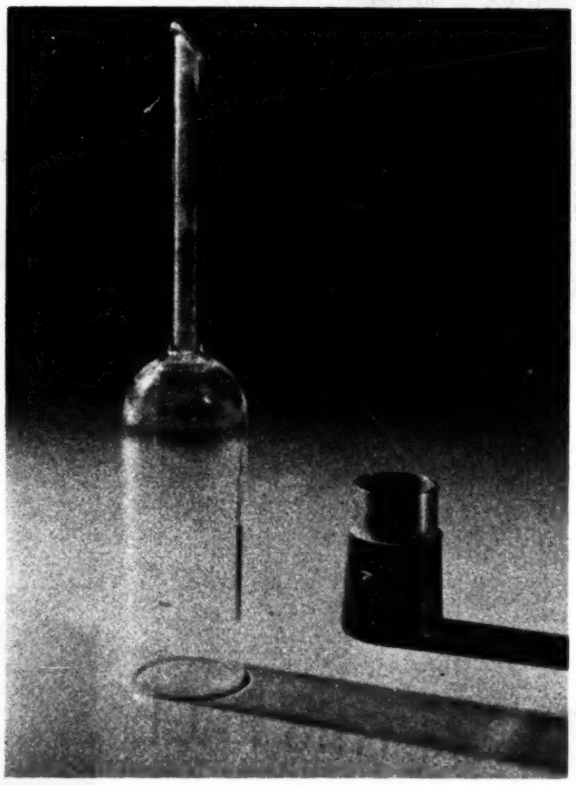


Fig. 8

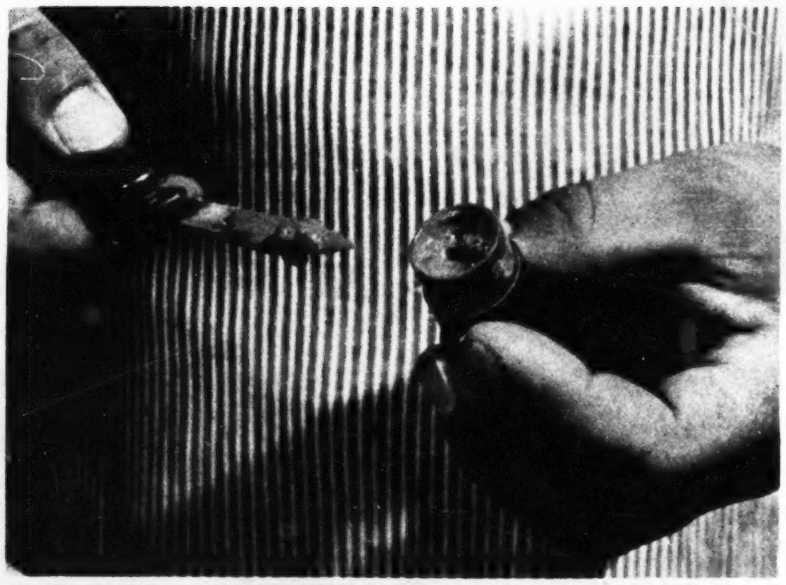


Fig. 9

Suitable slot widths may be obtained by cutting the slot with two hacksaw blades ganged side by side, or by using a 4-in. mill bastard file on edge.

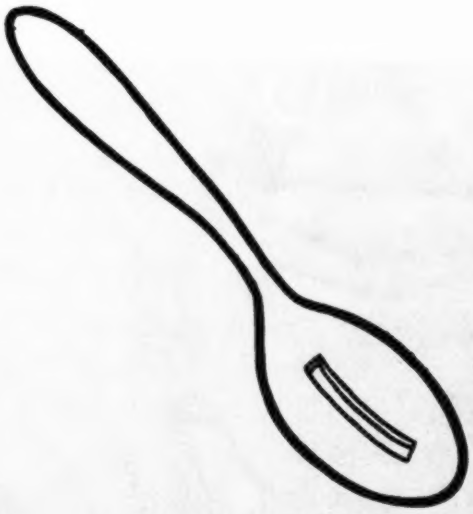


Fig. 10 Sample - splitting teaspoon

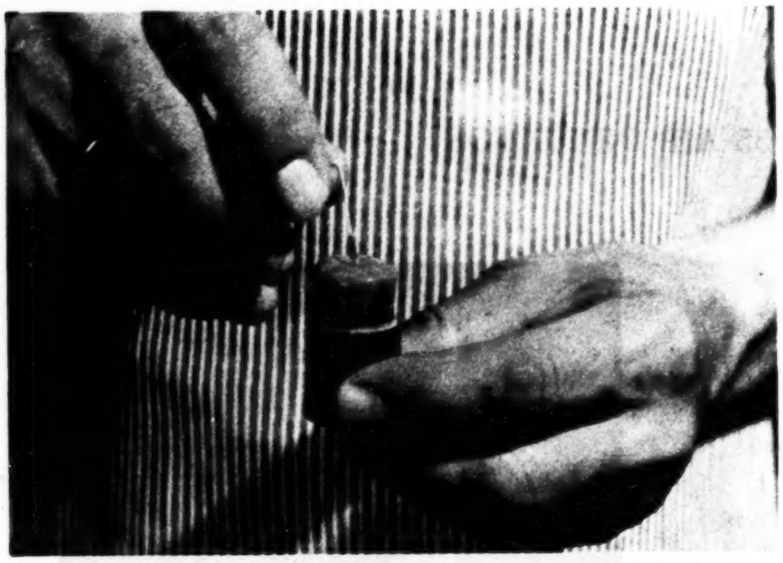


Fig. 11

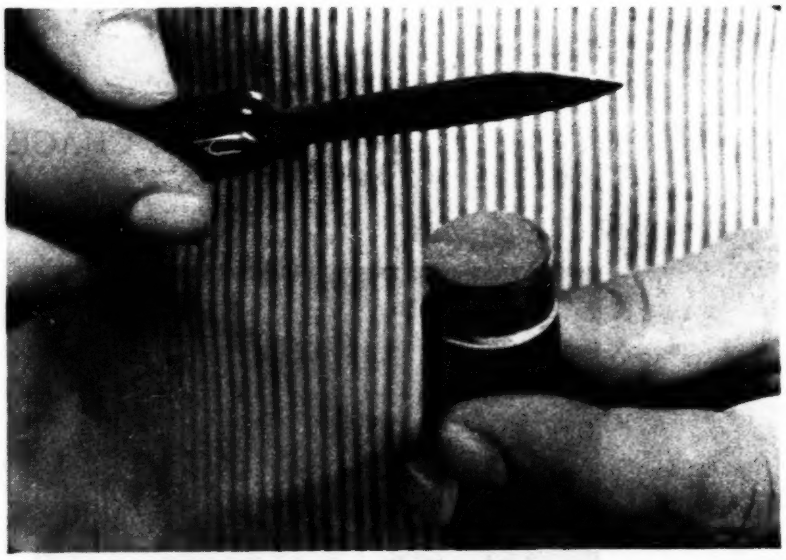


Fig. 12

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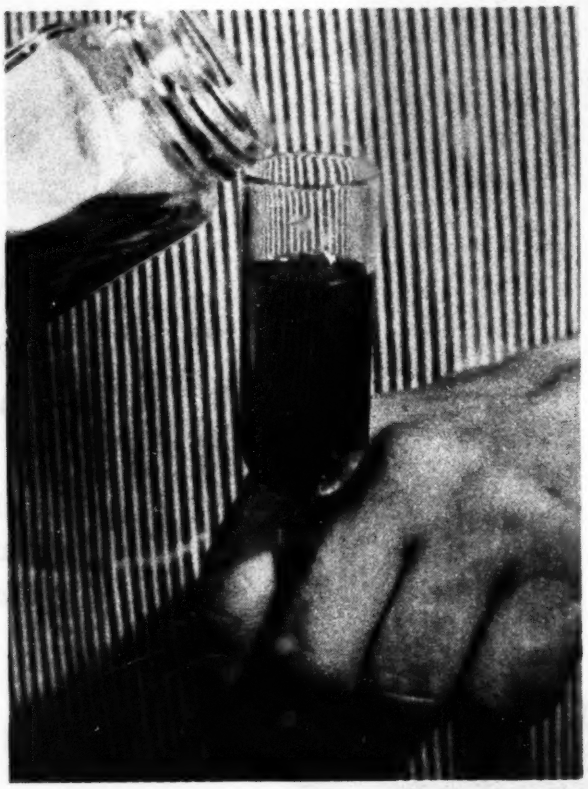
Fig. 13

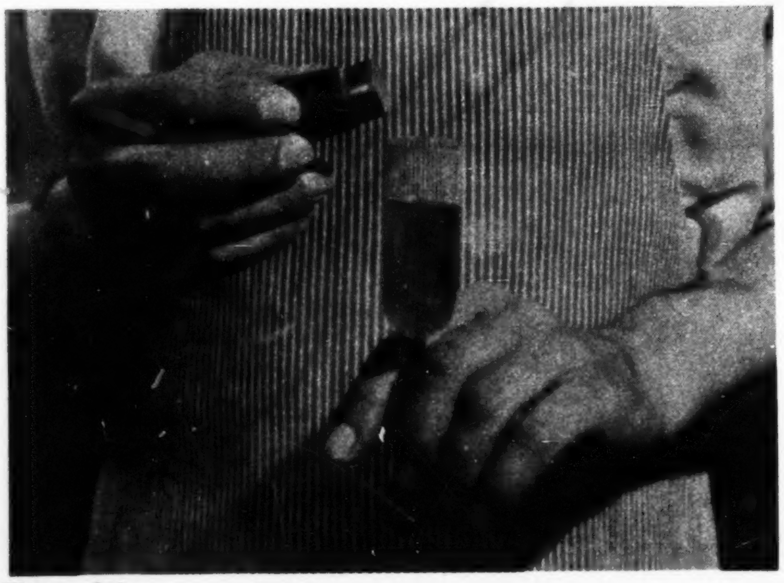
Fig. 14

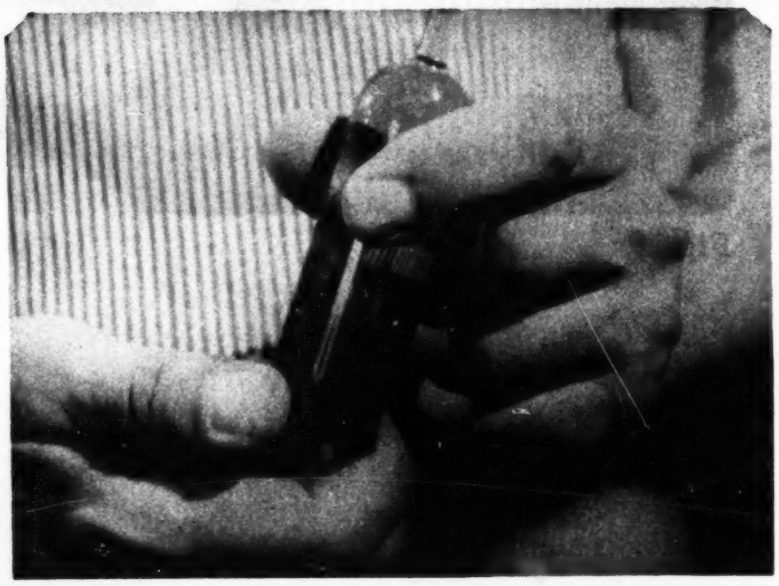
Fig. 15

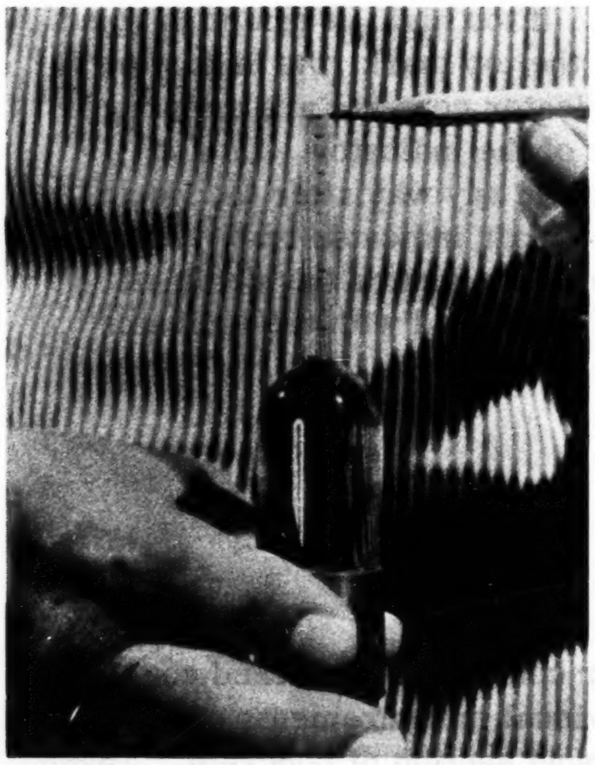

Fig. 16

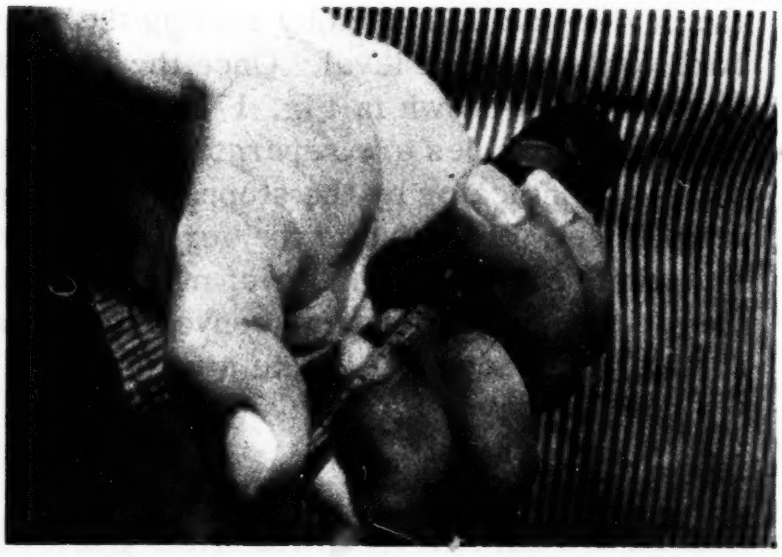

Fig. 17

## TABLE 2

## CONVERSION TABLE FOR CHACE AIR INDICATOR

**For following mortar content per cu. yd. multiply stem reading by appropriate constant to get percent air:**

**10 c.f. by 0.67**
**11 c.f. by 0.73**
**12 c.f. by 0.80**
**13 c.f. by 0.86**
**14 c.f. by 0.93**
**15 c.f. by 1.00**
**16 c.f. by 1.07**
**17 c.f. by 1.13**
**18 c.f. by 1.20**
**19 c.f. by 1.26**
**20 c.f. by 1.33**
**21 c.f. by 1.39**
**22 c.f. by 1.46**
**23 c.f. by 1.52**
**24 c.f. by 1.59**
**25 c.f. by 1.66**
**26 c.f. by 1.72**
**27 c.f. by 1.78**

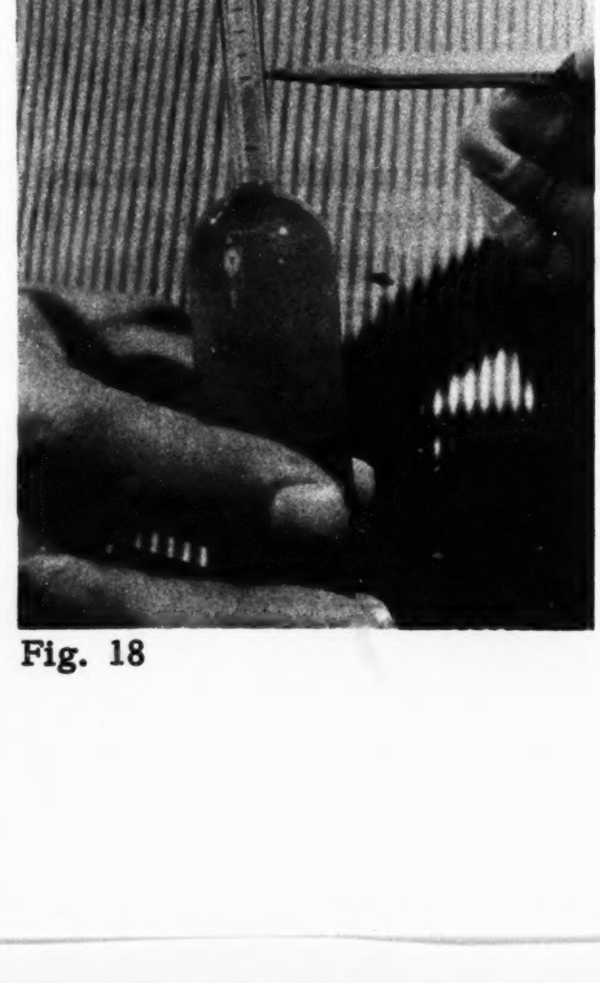

Fig. 18

body (Figs. 14 and 15) and twisted to effect a good seal. The top level of liquid in the device can be raised by seating the stopper harder. If too high, it can be drained back to the desired level. Once the liquid is zeroed at the top mark, the indicator is grasped as shown in Fig. 17 and shaken until the indicator contents are a slurry and all air bubbles are separated to coalesce at the top of the indicator. Do not grasp the indicator by the stopper or disturb the stopper in any way after the liquid level is set. To do so is the very best way to louse up an air indicator test. After agitation, count the number of marks the liquid level in the indicator has declined (Fig. 18). Use the mortar conversion table (TABLE 2) furnished with the indicator to determine actual concrete air content.

## TESTING FOR AIR IN HARDENED CONCRETE

The best means presently available for determining air contents of hardened concrete are the optical methods. They are based upon direct visual measurements of air voids which are intersected by the plane of a finely ground section of concrete. These methods provide information on air content, and size and distribution of air voids. They have provided the most significant data regarding factors governing the effectiveness of air in protecting concrete from frost damage.

### Linear Traverse Method

The linear traverse method involves measuring the chord lengths of air voids which are intersected by a line of traverse on a random plane sectioned through the concrete. The summation of the chord lengths across air voids represents the fractional proportion of air along the total length of traverse and is directly equivalent to the proportional volume of air void volume in the concrete.

### Modified Point Count Method

The modified point count method is similar to the linear traverse technique but varies by substituting a series of closely spaced points on a line of traverse rather than performing a continuous integration along the line. The number of points which fall on air voids represent the fractional proportion of air of the total number of points and is directly equivalent to the volumetric proportion of air in the concrete.

## DISCUSSION QUESTIONS

1. List and explain three methods of testing fresh concrete for air content.
2. Explain ways to test for possible changes in air content of plastic concrete.
3. List and explain two methods of checking air content in hardened concrete.

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